NBS

Technical Note No. 26

Boulder Laboratories

SURVEY OF CENTRAL RADIO PROPAGATION LABORATORY RESEARCH IN TROPOSPHERIC PROPAGATION 1948-1956

BY J. W. HERBSTREIT AND P. L. RICE

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

THE NATIONAL BUREAU OF STANDARDS

Functions and Activities

The functions of the National Bureau of Standards are set forth in the Act of Congress, March 3, 1901, as amended by Congress in Public Law 619, 1950. These include the development and maintenance of the national standards of measurement and the provision of means and methods for making measurements consistent with these standards; the determination of physical constants and properties of materials; the development of methods and instruments for testing materials, devices, and structures; advisory services to government agencies on scientific and technical problems; invention and development of devices to serve special needs of the Government; and the development of standard practices, codes, and specifications. The work includes basic and applied research, development, engineering, instrumentation, testing, evaluation, calibration services, and various consultation and information services. Research projects are also performed for other government agencies when the work relates to and supplements the basic program of the Bureau or when the Bureau's unique competence is required. The scope of activities is suggested by the listing of divisions and sections on the inside of the back cover.

Publications

The results of the Bureau's work take the form of either actual equipment and devices or published papers. These papers appear either in the Bureau's own series of publications or in the journals of professional and scientific societies. The Bureau itself publishes three periodicals available from the Government Printing Office: The Journal of Research, published in four separate sections, presents complete scientific and technical papers; the Technical News Bulletin presents summary and preliminary reports on work in progress; and Basic Radio Propagation Predictions provides data for determining the best frequencies to use for radio communications throughout the world. There are also five series of nonperiodical publications: Monographs, Applied Mathematics Series, Handbooks, Miscellaneous Publications, and Technical Notes.

Information on the Bureau's publications can be found in NBS Circular 460, Publications of the National Bureau of Standards ($1.25) and its Supplement ($1.50), available from the Superintendent of Documents, Government Printing Office, Washington 25, D.C.

NATIONAL BUREAU OF STANDARDS
Technical Note
26
September, 1959

Survey of Central Radio Propagation Laboratory Research in Tropospheric Propagation
1948-1956

by

J. W. Herbstreit and P. L. Rice

NBS Technical Notes are designed to supplement the Bureau's regular publications program. They provide a means for making available scientific data that are of transient or limited interest. Technical Notes may be listed or referred to in the open literature. They are for sale by the Office of Technical Services, U. S. Department of Commerce, Washington 25, D. C.

DISTRIBUTED BY
UNITED STATES DEPARTMENT OF COMMERCE
OFFICE OF TECHNICAL SERVICES
WASHINGTON 25, D. C.
Price $ $4.00

PREFACE

During 1954 a literature survey was conducted of research in tropospheric propagation with which the Central Radio Propagation Laboratory was directly concerned between 1948 and 1954. Originally a bibliography, the survey was first expanded to include abstracts of each paper and was then further expanded to include condensations or reprints of some papers not otherwise available.

This technical note is a revision of this survey, first printed in 1957 as NBS Report 3520, revised, updating the bibliography to 1956 and deleting reprints which have been published.

More extensive and current bibliographies are available in annual reports of the Boulder Laboratories of the National Bureau of Standards[1] and in two reports put out by the Meteorological Abstracts and Bibliographies[2]. Material in these reports, plus more extensive material is available as informal laboratory reports. A more current bibliography will appear shortly in an NBS Technical Note[3].

---

1. See for instance, the Fourth Annual Report of the Boulder Laboratories for year ending June 30, 1958.

2. Meteorological Abstracts and Bibliographies, Vol. 9, Nos. 9 and 10, September and October, 1958.

3. K. A. Norton et al, "Radio Studies of Atmospheric Turbulence," Vol. I and Vol. II. To be published as a National Bureau of Standards Technical Note sometime in 1960.

Preface to Revision, January 1957

This NBS report is being reissued with abstracts of additional papers arranged chronologically to follow page111. The author index and index of supplement titles will be found on pages 3a - 3e instead of pages 113 - 117 as in the original version. Where material included as a supplement to the original version is now available in the literature, the supplement has been deleted and an appropriate reference cited in its place.

SURVEY OF CENTRAL RADIO PROPAGATION LABORATORY RESEARCH IN TROPOSPHERIC PROPAGATION

Purpose

The main objective of the National Bureau of Standards tropospheric propagation research program described in this report has been to accelerate propagation studies in the frequency range from 30 to 6,000 megacycles, of particular interest to the Department of Defense and the Air Navigation Development Board and to provide basic information for application to specific problems.

Abstract

This report summarizes and abstracts publications concerned with the National Bureau of Standards tropospheric propagation research program dating back to the formation of the Central Radio Propagation Laboratory. Some technical papers are reproduced here as supplements to this report and excerpts from some of the longer technical reports are also included.

Introduction

The effects of climate, weather, and terrain on signal level and fading, height gain and antenna gain, and space and frequency diversity are often uncertain to a high degree, since every different climatological and terrain situation strongly influences time and space variations of tropospheric radio transmission loss. It has been determined that propagation data which will have useful application under the various conditions of climate and terrain encountered throughout the world must be obtained from a variety of geographical locations and over extended periods of time. Recordings for short periods of time are also of value. The analysis of pertinent tropospheric radio propagation data in the light of theoretical considerations promises to develop much more complete and accurate methods for describing and predicting tropospheric propagation over irregular terrain.

A large amount of data has been collected by the Tropospheric Propagation Research Section through subcontracts, including nearly a million hourly median values of field strength from all over the United States, and a great deal of analysis has been completed by CRPL. In order for this report to most adequately serve its purpose, activities will be reported under the following two section headings: (I) Abstracts of CRPL-Sponsored Publications and Reports, and (II) Status of Projects and Facilities.

Section (I) is divided into five subsections, and each of these is further subdivided according to subject matter. Following the subsections are additional reports arranged chronologically.

Within each of the twenty-two smallest divisions, reports are arranged chronologically. A publication listed under one of these headings is not listed in a later group, and publications are numbered consecutively from 1 to 306, including 174 progress reports prepared by subcontractors. An author index and an index of supplement titles will be found on pages 3a - 3e. Pages 112 -112t include a supplementary list of technical reports, numbered from 307 - 360.

Section II summarizes material in the thirteen previous quarterly progress reports which cannot be found in the technical reports and gives a short description of current projects, facilities, and compilations of data.

AUTHOR INDEX

Following the name of each author are the numbers of the reports in this list of which he is an author or co-author.

(Author Index Continued)

(Author Index Continued)

SUPPLEMENT INDEX

Supplement Index Continued

I. ABSTRACTS OF CRPL-SPONSORED PUBLICATIONS AND REPORTS.
(A few reports sponsored by other agencies are included)

A. Organization and Detailed Analysis of Data

(a) Propagation Characteristics

1. R. Bateman, E. F. Florman, and A. Tait, "A Source of Error in Radio Phase-Measuring Systems," Proc. IRE, Vol. 38, No. 6, p. 612, June, 1950.

ABSTRACT

When a mobile transmitter was moved between two points over different particular paths around reradiating structures, the measured total phase changes differed by $2\pi n$ radians, where n is an integer. If reradiation from a reflector is of the same order of magnitude as the radiation from an antenna, analysis of the resultant field shows that singularities occur, and each traverse of a closed path around a point of singularity gives a total phase change of 360°.

2. R. S. Kirby, "Simultaneous Mobile Measurement of Two VHF Broadcast Stations Over Irregular Terrain." presented at the URSI-IRE meeting of April, 1951 in Washington, D. C.

ABSTRACT

Two FM stations, one in Washington, D. C. and one in Baltimore, Maryland, were recorded while driving along a perpendicular bisector to the line joining the two stations for a distance of fifteen miles either side of the midpoint. This paper describes the data and how it was taken.

Comment

This paper is included here as Supplement I under the title, "Correlation in VHF Propagation over Irregular Terrain." Additional measurements of transmission loss were made at the same time as those reported here by traveling along a circular route at a relatively constant distance from a transmitting antenna with simultaneous transmission on two separate frequencies. These results as well as those described in Supplement I will be made available in a future report, titled, "Correlation in VHF Transmission Loss Measurements."

3. A. W. Straiton and C. W. Tolbert, "Experimental Discrimination of the Factors in VHF Radio Wave Propagation," University of Texas EERL Report No. 52, June 20, 1951.

ABSTRACT

This report describes the results of recent experiments performed at the Electrical Engineering Research Laboratory of the University of Texas for the purpose of determining the relative contributions of various possible propagation mechanisms affecting VHF radio field strengths at distances well beyond the optical horizon.

Height - gain curves of median level signals for propagation over distances of 78, 140, and 175 miles are reported, and their various features interpreted in terms of propagation by refraction, return from elevated layers, and scattering from regions of refractive index turbulence.

Measurements of cross-polarization provide additional information as to the relative contribution of various radio wave propagation factors. It was found that the cross-polarization ratios varied with absolute signal level. The characteristics of these ratios are, likewise, interpreted in terms of the contribution being made by each of the propagation mechanisms.

4. Kenneth Tritabaugh and James H. Chisholm, "Microwave Propagation Survey in Washington D. C. Area," NBS Report No. 1095, August 1, 1951.

ABSTRACT

Short-term 5,000 megacycle propagation surveys were made over four paths in the Washington, D. C. area, ranging from about 20 to about 37 miles in length.

Comment

This work was done according to an agreement between the Office of the Chief Signal Officer, Department of Defense, and CRPL, as a guide for a permanent microwave installation. As data at these frequencies are still rare, this report is included here in its entirety as Supplement II.

5. A. H. LaGrone, K. H. Jehn, and C. E. Williams, "Characteristics of 100 Mc Radio Propagation as a Function of Time and Distance," University of Texas EERL Report No. 56, August 31, 1951.

ABSTRACT

Continuous field-strength measurements were made on KIXL-FM, Dallas, Texas, at five stations located 50, 65, 106, 144, and 175 miles respectively along a path from Dallas to Austin. Curves of the hourly median signal level for each station are reported along with curves showing the hourly median signal as a function of distance. A qualitative analysis of the observed signal as a function of certain meteorological variables is made.

6. Irvin H. Gerks, "Propagation at 412 Mc from a High-Powered Transmitter," Proc. IRE, Vol. 39, No. 11, p. 1374, November, 1951.

ABSTRACT

Extended measurements are reported which indicate the existence of pronounced nocturnal superrefraction during an appreciable percentage of the summer and of very persistent scattering by atmospheric turbulence near the surface in all seasons. The measurements were taken over rolling mid-western terrain at a distance of about 100 miles. Mobile road tests were made to supplement the fixed-point measurements and to provide an approximate indication of the relation between field strength and distance. Aerial tests were made to show the effects of antenna height at large distances. Graphs are provided which show the effects of distance, terrain, antenna height, and time upon the field strength. The practical significance of the results in the broadcast and communication fields is indicated.

7. R. P. Decker, "Notes on the Analysis of Radio Propagation Data," Proc. IRE, Vol. 39, No. 11, p. 1382, November, 1951.

ABSTRACT

Statistical analysis of observations on the propagation of 410 Mc signals over distances of 86 and 134 miles is described. The equipment for indicating the percentage of time for which a number of preselected signal levels were exceeded is described.

8. J. S. Hill, G. V. Waldo, and Harold Staras, "VHF Tropospheric Recording Measurements of Plane and Circular Polarized Waves in the Great Lakes Area," given before the IRE Western Convention, San Francisco, California, August 22-24, 1951; abstract published in Trans. IRE PGAP-1, February, 1952, p. 42; entire paper published as FCC Mimeo No. 62838, April 16, 1651.

ABSTRACT

Continuous field strength recordings were made of the horizontal and vertical components as well as the circularly polarized field over a 125-mile path from Columbus, Ohio, to Hudson, Ohio. The results of these recordings are compared with recording of the propagation of plane polarized waves over the same path, as well as over other paths, one of them 50 per cent over water.

9. G. F. Montgomery, P. G. Sulzer, and Irvin H. Gerks, "An UHF Moon Relay," Correspondence, IRE, Vol. 40, No. 3, p. 361, March, 1952; see also NBS Tech. News Bulletin, Vol. 36, No. 3, p. 35, March, 1952.

ABSTRACT

On October 28 and November 8, 1952 a CW 418 Mc signal was successfully relayed from Cedar Rapids, Iowa to Sterling, Virginia, by using the moon as a reflector. A short description of this experiment is given here.

10. R. Bateman, D. K. Bailey, L. V. Berkner, H. G. Booker, G. F. Montgomery, E. M. Purcell, W. W. Salisbury, and J. B. Weisner, "A New Kind of Radio Propagation at Very High Frequencies Observable Over Long Distances," NBS Report No. 1172, September 28, 1951; see also Phys. Rev., Vol. 86, No. 2, p. 141, April 15, 1952; see also NBS Tech. News Bulletin, Vol. 36, No. 10, October, 1952.

ABSTRACT

The discovery and some results of a preliminary investigation of a new type of weak VHF propagation by means of the ionosphere is reported. This form of propagation appears to be observable over ranges out to about 2,000 kilometers from the transmitter but is likely to be masked by other kinds of propagation at distances much less than 1,000 kilometers. The initial experiments on a frequency of 49.8 Mc/sec reveal the uninterrupted presence of observable signal over a test path of 1,245 kilometers, irrespective of season, time of day, or geomagnetic disturbance, though showing dependence in intensity on these factors, and possibly on meteor activity as well. Some preliminary speculations suggest that the mechanism of this type of propagation may be scattering caused by ever-present irregularities in the E region, and an approximate transmission equation is derived in terms of parameters describing inhomogeneities in the E region. Measured signal intensities during periods of HF radio fadeouts associated with solar flares never show any reduction in signal. On the contrary, there is usually an enhancement of signal intensity accompanied by a simultaneous weakening of the background noise. This result suggests strongly that signals are returned from a part of the E region near or just below the absorption region for ordinary HF radio waves.

11. G. R. Chambers, J. W. Herbstreit, and K. A. Norton, "Preliminary Report on Propagation Measurements from 92 to 1046 Megacycles at Cheyenne Mountain, Colorado," NBS Report No. 1826, July 23, 1952.

ABSTRACT

A description is given of the facilities provided by the National Bureau of Standards on Cheyenne Mountain in Colorado and in its vicinity which are used for the measurement of the transmission loss on radio transmission circuits operated in the frequency range from 92 to 1046 Mc. Some preliminary results of these measurements are presented, together with tentative theoretical explanations.

Comment

Supplement IV reproduces certain tables and figures from this report which contain general information about the facilities and the characteristics of the transmission paths. Much more complete information will be found in NBS Circular 554, December, 1954, and a detailed description of data obtained from the Cheyenne Mountain Experiment will be found in a forthcoming final report to the Air Navigation Development Board.

12. R. S. Kirby, J. M. Taff, and H. S. Moore, "Measurement of the Effect of Irregular Terrain on VHF and UHF Directive Antenna Patterns," NBS Report No. 1719, June 3, 1952; see also Trans. IRE PGAP-3, p. 167, August, 1952.

ABSTRACT

Measurements of antenna patterns of directive antennas were made while driving around transmitters at relatively constant distances of 0.4, 10, and 30 miles. The transmitting antennas for pattern measurements were located at Fort Dix, N. J., and operated at frequencies of 49, 141.75, 239, and 460 megacycles. Most measurements were made at 12 and 15 feet above ground. Additional spot location measurements were made with a 460 megacycle corner reflector antenna.

13. A. P. Barsis, "Tropospheric Propagation Measurements Within the Radio Horizon Over Cheyenne Mountain Paths," presented at the Symposium on Tropospheric Wave Propagation Within the Horizon at USNEL, San Diego, California, March 30, to April 1, 1953.

ABSTRACT

The tropospheric propagation measurements being conducted by the Cheyenne Mountain Field Station of the Central Radio Propagation Laboratory include several optical paths, over which continuous recordings of field

strength are made on 100, 192.8, and 1046 Mc. Measurements at two fixed receiving sites located on a path running 105° east of true north from the transmitter site on Cheyenne Mountain are analyzed, and the results of 12 months of continuous recordings are presented in the form of charts showing diurnal and month-to-month variations of hourly median values of received field.

An examination of the frequency of occurrence of prolonged space-wave fadeouts shows that they are substantially more prevalent in summer than in winter, and that they occur principally at night.

Comment

This report is reproduced here as Supplement V.

14. H. B. Janes, "An Analysis of Within-the-Hour Fading in 100-1000 Mc Transmissions," presented at the April, 1953 meeting of URSI-IRE in Washington, D. C.

ABSTRACT

An analysis is made of the fading range of 100 to 1000 megacycle transmissions received both within and beyond the radio horizon in measurements made during August, 1952 over the various Cheyenne Mountain Field Station paths and over the Cedar Rapids, Iowa - Quincy, Illinois path. Fading range is defined as the ratio in decibels of the signal levels exceeded 10 per cent and 90 per cent of an hour. For each of the four frequencies studied, the extent to which median fading range and median signal level depend on the angular distance and time of day is shown in the form of graphs and recording samples.

Comment

This report is reproduced here as Supplement XII.

15. K. A. Norton and H. B. Janes, "The Rate of Fading in Tropospheric Propagation," presented at the 11th General Assembly of the URSI at The Hague in August 1954.

ABSTRACT

In this paper an analysis of tropospheric fading is presented. Fading rate is defined to be the number of times per minute that the envelope of the received field crosses its median level with a positive slope. It is shown that this definition of fading rate not only provides a quantity which is easily determined from the experimental data but also provides a quantity which is readily identifiable with the parameters of the propagation medium. It is also shown that this definition is as useful in the intermediate range of distances where the scattered component of the received field is comparable to the diffracted component as it is at the larger angular distances where the scattered component predominates.

Comment

This report is reproduced here as Supplement VII.

16. A. P. Barsis, B. R. Bean, J. W. Herbstreit, K. O. Hornberg, and K. A. Norton, "Propagation of Radio Waves Over Land at 1046 Mc," NBS Report No. 2494, May 1, 1953.

ABSTRACT

This report presents experimental data on 1046 Mc obtained at the Cheyenne Mountain Field Station for the period February 1, 1952, through January 31, 1953. The report includes an analysis of diurnal and seasonal variations in hourly median signal levels, analysis of variations in instantaneous signal levels, and the analysis of prolonged space-wave fadeouts within the radio horizon for the period investigated. Also included are an analysis of the effects of irregular terrain at points within the radio horizon, including estimates of the expected effective gains of large antenna arrays

the required spacing for diversity arrays, and the effective intelligence-bearing bandwidths of the propagation paths. Finally, as a result of a recent investigation of propagation over high mountain ridges, an analysis is presented of the "obstacle gains" expected at 1000 Mc in mountainous terrain.

Comment

With figures, this report is 134 pages. Pages 1 through 8 of the text and figures 1, 2d, 2e, 3a, 3d, 4a, 4b, 5a, 6k, 9b, 10a, 10b, 11a, 11b, 11c, 12a, 12b, 12e, 14a, 14b, 15a, 15b, 15d, and Appendix I of NBS Report No. 2494 are included here as Supplement VI.

17. M. T. Decker and H. B. Janes, "418 Mc Propagation Measurements Over the Cedar Rapids - Quincy Path," NBS Report No. 2527, May 18, 1953.

ABSTRACT

The transmitting, receiving, and recording facilities used in propagation measurements made at 418 Mc during the period May to December, 1951, over the 133.9-mile Cedar Rapids - Quincy path are described. The discussion of the received signal power data includes an analysis of variations in instantaneous signal level, as well as analysis of diurnal and seasonal variations in hourly median signal levels.

Comment

This report is reproduced here as Supplement III.

18. A. P. Barsis, "Comparative 100 Mc Measurements at DistancesFar Beyond the Radio Horizon," 1954 IRE Convention Record, Part 2, Antennas and Communications, p. 98; see also NBS Report No. 2539, May 26, 1953.

ABSTRACT

Results of 100 Mc measurements are evaluated in terms of distributions of hourly median values of transmission loss. Transmitters were located at elevations of approximately 6200, 8800, and 14,100 feet above mean sea level on the eastern slope of the Rocky Mountains. Receiving sites were located at distances of 230 and 400 miles from the transmitters. Various types of antennas were employed for transmitting and receiving. The results of studies of fading rate and fading range are reported for the 400-mile site by comparing signals received simultaneously on two different antennas. These results are compared to those expected from the application of the tropospheric scattering theory.

19. E. K. Smith, "The Effect of Sporadic E on Television Reception," Trans. IRE PGAP-2, March, 1952, pp. 54-61; see also NBS Report No. 1907, September 8, 1952, and Radio Electronics, Vol. 24, No. 6, June, 1953.

ABSTRACT

A study of 466 reports of high and low band television reception greater than 200 miles shows both ionospheric and tropospheric propagation. A rather clear line may be drawn between the two, however. The distribution of reports with distance indicates that those with transmission paths between 200 and 500 miles are tropospherically propagated, whereas those between 500 and 1500 miles are propagated by single hop reflection from the sporadic E region of the ionosphere.

20. F. H. Dickson, J. J. Egli, J. W. Herbstreit, and G. S. Wickizer, "Large Reductions of VHF Transmission Loss and Fading by the Presence of a Mountain Obstacle in Beyond Line-of-Sight Paths," Proc. IRE, Vol. 41, No. 8, pp. 967-969, August, 1953; see also NBS Tech. News Bulletin, Vol. 37, No. 12, P. 177, December 1953.

ABSTRACT

A detailed investigation of the probable mode of propagation in VHF propagation over mountain obstacles has been made. Theory indicates that tremendous gain in received signal strength--above what is obtained over a smooth spherical earth--may be expected. Experimental verification of the principles involved is reported. In addition, the fading was found to be small and even essentially non-existent on certain very long obstructed paths.

21. C. R. Ammerman and R. L. Riddle, "A Preliminary Study of Fading of 100 Mc/s FM Signals," Trans. IRE, Vol. AP--2, p. 30, January, 1954.

ABSTRACT

A statistical study is made of short-period fading over a mountainous path of about 120 miles under typical midday conditions. Signal amplitudes have an essentially Rayleigh distribution; amplitude variations have a Gaussian distribution. Speed of fading and values of effective wind velocity are determined statistically; the latter are compared with measured values.

22. R. S. Kirby, J. C. Harman, F. M. Capps, and R. N. Jones, "Effective Radio Ground Conductivity Measurements in the United States," NBS Circular 546, February 26, 1954.

ABSTRACT

Maps are presented showing the results of effective radio ground conductivity measurements made by various broadcasters and consulting engineers throughout the United States. The need for such detailed maps has been indicated by the lack of reliability inherent in the use of general-area conductivity maps and by studies of the correlation of effective ground conductivity measurements with surface soil conditions. Over 7,000 radials are shown on the maps, and provisions have been made for entering new measurements, as the results become available, for possible future publication. Due to the complexity of ground-wave propagation over an inhomogeneous earth, the determination of effective ground conductivity over a given radial strictly applies only at the frequency at which the measurements were made.

23. F. M. Capps, R. N. Jones, and R. S. Kirby, "An Analysis of Effective Radio Ground Conductivity by Soil Types for the United States," in preparation.

ABSTRACT

A study has been made of the correlation between soil type and the ground conductivity effective in surface wave propagation, using over 7,000 separate measurements of effective ground conductivity made in various parts of the United States. The soil types were obtained from the "Atlas of American Agriculture," a publication of the U. S. Department of Agriculture, which lists 243 soil types with detailed sectional maps showing their location. Predictions are most reliable in the case of the 42 soil types over which the measurements of about 5 or more broadcast stations were available.

24. R. S. Kirby, H. T. Dougherty, and P. L. McQuate, "Obstacle Gain at 60 Mc Over Pikes Peak," in preparation.

ABSTRACT

Transmission loss measurements were made over various paths of approximately 100 miles in length in the Pikes Peak area of Colorado in order to investigate obstacle gain phenomena in a mountainous region. The transmissions of a Denver television station, KFEL-TV, operating on Channel 2 were used in this study. Measurements were made at five-mile intervals at seven locations between Canon City and Pueblo, Colorado, such that three transmission paths were west of Pikes Peak, one was directly over Pikes Peak, and three were east of Pikes Peak.

In addition, recordings were made for prolonged slow-time-base recording periods for a path directly over Pikes Peak and for a path west of Pikes Peak. For the Pikes Peak path a strong signal and reduced fading effect, relative to that for other paths, was observed. The measurements were compared with expected values calculated by means of the Fresnel-Kirchoff scatter diffraction theory and its extension provided by Schelleng, Burrows, and Ferrell.

25. A. P. Barsis, J. W. Herbstreit, and K. O. Hornberg, "Cheyenne Mountain Tropospheric Propagation Experiments," NBS Circular No. 554, December, 1954.

ABSTRACT

This circular describes the facilities of the National Bureau of Standards Cheyenne Mountain Field Station in Colorado, the type of measurements being taken, and the type of data analyses being made. Propagation path characteristics are summarized in detail. The circular is expected to be a basic reference concerning the unique National Bureau of Standards facilities available for tropospheric measurements.

26. A. P. Barsis, B. R. Bean, and P. L. Rice, "UHF Tropospheric Propagation," Final Report for the Air Navigation Development Board, in preparation.

ABSTRACT

An investigation of 960 to 1600 megacycle radio wave propagation initiated by the Air Navigation Development Board has been directed by the Central Radio Propagation Laboratory of the National Bureau of Standards since 1950. In view of the evidence of interference fields well beyond radio line-of-sight, the Cheyenne Mountain Field Station was established in Colorado Springs, Colorado, to investigate simulated air-to-ground transmissions, not only within radio line-of-sight, but also far beyond line-of-sight.

Two sections of this report briefly describe the Cheyenne Mountain project and summarize the data obtained in 1952 and 1953. Another section explains prolonged space-wave fadeouts in detail, and the last section of the report presents theoretical curves which compare the effects of earth reflection and of space-wave fadeouts at 100 and at 1000 megacycles on the operation of a CAA DME facility.

27. L. E. Vogler, "Summary of Transmission Loss Measurements of KIXL-FM at 176 Miles Over Several Years," in preparation.

ABSTRACT

This report summarizes the results of an interesting program of measurements undertaken by the University of Texas under contract with the National Bureau of Standards. Digested mainly in the form of cumulative distributions of hourly median field strengths for various arbitrary "time blocks," some of the statistical characteristics of measurements extending over twenty-four hours a day and several years are shown.

28. A. P. Barsis, B. R. Bean, and K. O. Hornberg, "A Comparison of UHF-VHF Propagation Phenomena Over Water and Over Land Transmission Paths Within the Radio Horizon," in preparation.

ABSTRACT

Measured transmission loss data in the 100 Mc and 1000 Mc range are available over two paths with high transmitting terminals and receiving locations at low grazing angles just within the radio horizon. One path is largely over water along the Pacific coast, and the other is over relatively smooth prairie land in eastern Colorado.

Results of measurements are evaluated for both paths in terms of hourly median values of transmission loss and its diurnal and seasonal variations. A comparison of duration and

depth of prolonged space-wave fadeouts observed over the two paths shows that these fadeouts are more frequent, but of shorter duration, for the overwater path. This phenomenon may be explained by interpretation of concurrent meteorological observations over the two paths and the general climatology of the two areas involved.

29. P. L. Rice, J. S. Hill, and G. E. Schafer, "Long-Term Monitoring of Two FM Stations at 40 sites 85 and 125 Miles from Columbus, Ohio," in preparation.

ABSTRACT

Two long-term mobile recording surveys have been conducted by the United Broadcasting Company under contract with the National Bureau of Standards. These surveys are unique, in that they sample in time and over a number of locations in such a way that time and terrain variances are separable. A report is in progress to show the results of analysis of these data.

(b) Prediction Curves.

30. E. W. Allen, W. C. Boese, and H. Fine, "Summary of Tropospheric Propagation Measurements and the Development of Empirical VHF Propagation Charts," Reference D to the Report of the FCC Ad Hoc Committee for the Evaluation of FM and TV Propagation Factors between 50 and 250 Mc, FCC Mimeo No. 36728, May 26, 1949, T. I. D. Report No. 2.4.6.

ABSTRACT

A detailed description is given here of the preparation of the FCC Ad Hoc Committee VHF prediction curves which are included in this report and in Volume I of the Report of the FCC Ad Hoc Committee.

31. Volume I to the Report of the FCC Ad Hoc Committee for the Evaluation of the Radio Propagation Factors Concerning the Television and Frequency Modulation Broadcasting Services in the Frequency Range Between 50 and 250 Mc, FCC Mimeo 36830, May 31, 1949.

ABSTRACT

Generalized tropospheric propagation curves are presented for adoption as the best estimates of VHF field strengths to be expected under average conditions along the Atlantic seaboard of the United States. In the analysis leading to the curves, the Ad Hoc Committee considered only variations expressed as levels exceeded for various percentages of the total period of recording. The curves are intended to represent fields exceeded for specified percentages of time throughout the broadcast day and throughout the year.

32. K. A. Norton, M. Schulkin, and R. S. Kirby, "Ground-Wave Propagation Over Irregular Terrain at Frequencies Above 50 Mc," Reference C to the Report of the FCC Ad Hoc Committee for the Evaluation of FM and TV Propagation Factors Between 50 and 250 Mc, June 6, 1949.

ABSTRACT

In this report terrain correction factors are presented for use in calculating field strength in connection with the problem of television broadcast station allocation. These factors, which are shown as a function of the frequency and distance (out to 70 miles) are to be applied to field strength calculations based on smooth-earth ground-wave propagation theory.

33. Deleted.

34. P. L. Rice, F. T. Daniel, W. V. Mansfield, and P. J. Short, "Radio Transmission Loss versus Angular Distance and Antenna Height at 100 Mc," presented at the National Bureau of Standards Boulder Laboratories Dedication Program, September 8 - 14, 1954.

ABSTRACT

This report describes curves of radio transmission loss and the long-term variability in time of transmission loss as a function of angular distance and transmitting and receiving antenna height, with one antenna fixed at thirty feet. Observations between 92 and 108 Mc on which the curves are based extend over a period of several years and are distributed geographically over the area of the United States east of the Rocky Mountains. Data from the Pacific coast are shown for comparison with the curves.

Comment

This report is reproduced here as Supplement IX.

35. P. L. Rice and F. T. Daniel, "Radio Transmission Loss versus Distance and Antenna Height at 100 Mc," presented before the Spring URSI-IRE meeting in Washington, D. C., in 1952; presently being considered by the Papers Review Committee of the IRE Professional Group on Antennas and Propagation for publication in April, 1955.

ABSTRACT

This report describes curves of transmission loss versus distance and antenna height derived from an analysis of approximately 159,000 hourly median field strength observations between 90 and 110 Mc. These observations extend over a period of several years and are distributed geographically over the whole United States. The curves contained in this report are believed to be more precise for engineering use than the FCC Ad Hoc Committee curves published in 1949.

Comment

This report is included here as Supplement VIII.

(c) Radio Meteorology.

36. D. L. Randall and M. Schulkin, "A Survey of Meteorological Instruments Used in Tropospheric Propagation Investigations," CRPL Report 2-1, July 21, 1947.

ABSTRACT

The Central Radio Propagation Laboratory of the National Bureau of Standards, in order to evaluate tropospheric propagation data with regard to the effect of weather, is obtaining detailed meteorological information. The following is a summary of existing low-level meteorological techniques and instruments in use or under development which measure the meteorological elements affecting microwave propagation in the lowest 5,000 feet of the atmosphere. Measurements of these elements are necessary in order to compute the refractive index and the liquid water attenuation of the air for microwave radio propagation.

37. G. Birnbaum, J. Franeau, "Measurement of the Dielectric Constant and Loss of Solids and Liquids by a Cavity Perturbation Method," Jour. Appl. Phys. Vol. 20, p. 817, August, 1949.

ABSTRACT

The changes Δf, ΔQ in the resonance frequency and Q of a cavity resonator when a small cylindrical sample of a solid is inserted are measured by a method in which the resonance curve, together with a pair of calibrated variable frequency markers, are displayed on a cathode ray oscilloscope screen. Formulas due to Bethe and Schwinger relate Δf and ΔQ to the complex dielectric constant of the solid. A Block diagram of the equipment is given. Typical results are tabulated and compared with that of Bleaney, Loubser, and Penrose. The method described extends the usefulness of Sproull and Linder's method by its sensitive technique for measuring small frequency differences.

38. Howard E. Bussey, "Microwave Attenuation Statistics Estimated from Rainfall and Water Vapor Statistics," Proc. IRE, Vol. 38, No. 7, p. 781, July, 1950; see also NBS Tech. News Bulletin, Vol. 33, No. 12, p. 144, December, 1949.

ABSTRACT

Annual probability curves are obtained for values of total atmospheric attenuation over a 50 km path and a 1 km path at Washington, D. C. These results are obtained by analyzing the available meteorological data, though these are usually ill-suited to the purpose; theoretical coefficients are used for converting into radio attenuation values. Extension of the results to other portions of the country is discussed.

39. J. R. Gerhardt, C. M. Crain, "Measurements of the Parameters Involved in the Theory of Radio Scattering in the Troposphere," Proc. IRE, Vol. 40, No. 1, p. 50, January, 1952.

ABSTRACT

Booker and Gordon have recently proposed a theory of radio scattering in the troposphere. Using atmospheric inhomogeneities in refractive index, the scattered power was shown to be a function of the intensity and scale of the existing turbulent variations. Lacking experimental data on the nature of the refractive index variations which may be present in the atmosphere, they predicted the magnitude of refractive index changes on the basis of limited temperature fluctuation measurements. Measurements have been made of refractive index and associated temperature fluctuations by the Electrical Engineering Research Laboratory of the University of Texas since 1948 with a somewhat detailed study being made from 10 inches to 50 feet above the ground since December, 1949. This paper includes a brief discussion of the recording refractometer and recording thermometer used for these studies, a meteorological analysis of the problem, and tracings of the refractive index and temperature fluctuations for several various conditions of the lower atmosphere.

40. G. Birnbaum and S. Chatterjee, "The Dielectric Constant of Water Vapor in the Microwave Region," Jour. Appl. Phys., Vol. 23, p. 220, February, 1952.

ABSTRACT

Using a cavity method described previously, measurements were made over the temperature range 32° - 103°C at a frequency of 9.28 kmc and at the single temperature of 24.5° C at 24.8 kmc. Results are discussed.

41. Morris Schulkin, "Average Radio-Ray Refraction in the Lower Atmosphere," CRPL Report 2 - 2, August 11, 1947; see also Proc. IRE, Vol. 40, No. 5, p. 554, May, 1952.

ABSTRACT

Existing corrections for atmospheric refraction in radio-field intensity computations are reviewed with respect to their application to computation of ray bending. A practical scheme is presented for calculating atmospheric refraction of radio-frequency rays numerically from radiosonde data. Ray-bending computations are made for a range of climatological conditions for rays passing entirely through the atmosphere and arriving or departing tangentially at the earth's surface. Some discussion is included regarding the uncertainty in refractive-index computations from meteorological sounding data.

42. G. Birnbaum, H. E. Bussey, and R. R. Larson, "The Measurement of Variations in Atmospheric Refractive Index," NBS Report 1874, August 19, 1952.

ABSTRACT

A recording microwave refractometer has been adapted for measuring variations in the refractive index of the atmosphere and for determining scale of refractive index inhomogeneities. The following features are discussed: cavity design and arrangement, response time of instrument, and calibration.

With the aid of a small wind tunnel, the thermal errors attendant on sampling the atmosphere with cavity resonators have been investigated. These errors arise because of a change in temperature of the air sample on coming in contact with the cavity, and because of thermal expansion effects on the cavity frequency. The former effect may amount to 20 per cent; methods for reducing latter are suggested. Other possible errors in the measurement of ri, those due to condensation and adsorption of water vapor, are apparently not significant.

Observations during August, 1941, were made with refractometers and meteorological equipment installed on two levels

of a 420-foot tower at the Brookhaven National Laboratory, Long Island, New York. It has been found from a preliminary data analysis that ri variations were caused mostly by variations in water vapor density. The ri data at 410 feet show a wide range of Fourier components, corresponding to wavelengths of roughly 10 to 1,000 meters.

43. K. Toman, W. G. Albright, and E. C. Jordan, "Meteorological Effects of VHF Propagation," Trans. IRE PGAP, p. 20, December, 1952.

ABSTRACT

It is the purpose of this paper to describe briefly the results of one and one-half years' recording of FM and TV stations in Illinois by the University of Illinois. An attempt has been made to isolate certain modes of propagation by means of the radiosonde data, and in terms of the corresponding signal levels. It will be shown that when atmospheric conditions are more or less uniform over the path, it is possible to ascribe to certain signal levels specific atmospheric conditions which are described in terms of the gradient of the dielectric constant.

44. B. R. Bean, "Geographical and Height Distribution of the Gradient of Refractive Index," NBS Report No. 1720, May 20, 1952; see also Proc. IRE, Vol. 41, No. 4, pp. 549, 550, April, 1953.

ABSTRACT

Charts are presented of the February and August distribution of effective earth's radius factor over the United States. Also included is a chart showing the distribution of refractive index gradient for warm, temperate and cold climates.

45. G. Birnbaum and H. E. Bussey, "Measurement of Variations in Atmospheric Refractive Index with an Airborne Microwave Refractometer," Jour. Res. NBS Vol. 51, p. 171, October, 1953.

ABSTRACT

The cavity-resonator refractometer described is essentially the same as that used for previous measurements of 1951 (Birnbaum). Observations were made at heights up to 10,000 feet; examples of strip records obtained are reproduced. The variations were negligible for distances less than 5 m. Large increases of refractive index were observed on entering cumulus clouds, and intense fluctuations were noted within the clouds.

46. B. R. Bean and F. M. Meaney, "The Monthly Refractive Gradient for the United States and Its Application to Predicting the Geographical and Annual Trend of VHF Transmission Loss," Proceedings of the Conference on Radio Meteorology, the University of Texas, November 9-12, 1953, Supplement III-2.

ABSTRACT

Climatic maps of monthly average refractivity gradient are presented for the United States for the hours 0300 and 1500 GCT. These maps are shown to follow a regular climatic pattern. The refractivity gradients as obtained from individual monthly maps are then correlated with the monthly median transmission loss of all available VHF propagation paths. The usefulness of this approach for the prediction of VHF transmission loss is described.

47. L. J. Anderson and E. E. Gossard, "Prediction of the Nocturnal Duct and Its Effect on UHF," Proc. IRE, Vol. 41, January, 1953.

ABSTRACT

A method is described for predicting diurnal variation in UHF field strengths, which is based on the micrometeorology governing the nighttime refractive-index profiles. Using surface meteorological data from past years, predictions are made of the probability distribution of the diurnal field variations to be expected on 100 and 1,000 Mc over CRPL links in Colorado. The predictions are compared with field-strength observations taken in 1952, and the agreement is encouraging.

48. D. L. Randall, "A Study of Some of the Meteorological Effects on Radio Propagation at 96.3 Mc Between Richmond, Virginia, and Washington, D. C.," NBS Report No. 2393, March 26, 1953; see also the Bulletin of the American Meteorological Society, February, 1954.

ABSTRACT

This study was made to investigate the relationship of surface meteorological data and corresponding surface refractive indices to radio field strengths in the FM frequency band. For meteorological observations during which wind speeds were equal to or greater than ten miles per hour, and when fronts, low overcast clouds (less than 5,000 feet), rain, thunderstorms, and fogs were excluded, an 0.70 correlation coefficient was found between hourly surface refractive index and hourly median field strength over a Washington - Richmond path at a frequency of 96.3 Mc.

49. Bradford R. Bean, "Prolonged Space-Wave Fadeouts at 1046 Mc Observed in Cheyenne Mountain Propagation Program," Proc. IRE, Vol. 42, No. 5, pp. 848-853, May, 1954.

ABSTRACT

During the first year of continuous operation of the Cheyenne Mountain propagation program, recordings of 1046 Mc fields at receiving locations within the radio horizon

have exhibitied "fadeouts" or prolonged periods of attenuation often in excess of 20 db below the monthly median level and lasting from a minute up to several hours. The occurrence of these fadeouts has been found to coincide with widespread superrefraction, as evidenced by enhanced signals beyond the radio horizon and ground modification of the refractive index profile.

50. B. R. Bean, "Estimation of the Annual Geographic, and Terrain Variances of 100 Mc Transmission Loss," presented at the National Bureau of Standards Boulder Laboratories Dedication Program, September 8-14, 1954.

ABSTRACT

Regression lines are determined for use in predicting the annual cycle and the geographical variations of monthly median values of transmission loss on frequencies near 100 megacycles in terms of an atmospheric parameter, ΔN, which is the difference of the values of refractivity at the surface and at one kilometer above the surface.

Comment

This report is reproduced here as Supplement X under the title, "Some Applications of the Monthly Mean Refractivity Gradient in Tropospheric Propagation."

(d) Cosmic Radio Noise.

51. J. W. Herbstreit, "Cosmic Radio Noise," Advances in Electronics, Vol. 1, Academic Press, Inc. Publishers, New York City, 1948.

ABSTRACT

The fact that cosmic and solar radio noise is arriving at the earth with sufficient intensity to determine the lowest usable field intensities for radio communication services throughout a wide band of frequencies is now well established. This report reviews observations of cosmic noise made up to the time of writing and presents in graphical form estimates of effective noise figures for receivers including effects of cosmic, ground, and receiver noise using half-wave receiving antennas one-quarter wavelengths above ground.

52. J. W. Herbstreit and Joseph R. Johler, "Frequency Variation of the Intensity of Cosmic Radio Noise," Correspondence. Nature, Vol. 161, No. 4092, April 3, 1948.

ABSTRACT

The intensity of cosmic radio noise (as received on horizontal half-wave dipole antennas one-quarter wave-length above ground) has been measured at 25 Mc and 110 Mc using identical noise diode calibration methods. Results of these measurements are shown in a graph, and given at 110 Mc for antennas oriented both normal to and parallel to the geographic meridian.

53. G. Reber, "Cosmic Static," Proc. IRE, Vol. 36, p. 1215, October, 1948.

ABSTRACT

The results of a survey of the galaxy made at a frequency of 480 Mc are compared with previous results for 160 Mc. The apparatus used is described briefly. The principal new findings are:

(1) a projection from Sagittarius in the direction of the north galactic pole
(2) a supplementary small rise in Aquilla
(3) a splitting of the maxima in Cygnus and Orion each into two parts.

54. H. V. Cottony, J. R. Johler, "Cosmic Radio Noise Intensities in the VHF Band," Proc. IRE, p. 1053, September, 1952. (Original -- May 23, 1951; Revised -- April 30, 1952).

ABSTRACT

During 1948 and 1949, the NBS conducted continuous, broad-directivity measurements of the cosmic radio noise intensities at frequencies between 25 and 110 Mc. Their purpose was to evaluate the importance of this noise from the standpoint of its interference with radio communication. The results show a regular daily variation in noise corresponding to the movement of the principal sources of cosmic radio noise across the antenna receiving pattern. This normal cosmic noise intensity pattern was found to be constant within the limits of the accuracy of the measurements. It was found convenient to present the results in terms of daily maxima and minima which bracketed the daily variations. No measurable change in these limits was observed in the course of these measurements.

Besides the normal cosmic radio noise, periods of abnormal high noise levels, generally associated with periods of unusual solar activity, were observed and recorded.

(e) General.

55. K. A. Norton, "Propagation in the FM Broadcast Band," Advances in Electronics, Vol. 1,pp. 381-421, Academic Press, 1948.

CONTENTS

(1) Introduction
(2) The Interference Due to Long Distance Ionospheric Propagation.
(3) The Effects of Radio Noise on Broadcast Reception.
(4) The Effects of Antenna Height and Terrain on the Effective Transmission Range Over a Smooth Spherical Earth.
(5) The Effects of Irregularities in the Terrain.
(6) The Systematic Effects of Terrain and of Tropospheric Ducts.

(7) The Tropospheric Waves Resulting from Reflection at Atmospheric Boundary Layers.
(8) The Combined Effects of Ducts and of Random Tropospheric Waves.
(9) The Calculated Service and Interference Ranges of FM Broadcast Stations.
(10) The Efficient Allocation of Facilities to FM Broadcast Stations.
(11) The Optimum Frequency for an FM Broadcast Service.

56. "Extension of FM Broadcast Range," NBS Tech. News Bulletin, Vol. 32, No. 4, p. 37, April, 1948.

ABSTRACT

Experimental research conducted by K. A. Norton of the National Bureau of Standards indicates that the reliable service areas of FM broadcast stations using transmitters now available may be extended far beyond the horizon. This paper discusses ways of increasing service range.

57. "Bibliography of Reports on Tropospheric Propagation," CRPL Report No. 2-3, July 23, 1948.

58. "New Site for Radio Propagation Laboratory," NBS Tech. News Bulletin, Vol. 34, No. 3, p. 32, March, 1950.

ABSTRACT

Plans are noted for the building of a new radio laboratory in Boulder, Colorado.

59. "NBS Research in Navigation," NBS Tech. News Bulletin, Vol. 34, No. 6, p. 80, June, 1950.

ABSTRACT

This paper gives some idea of the scope of the Bureau's work in the field of aids to navigation.

60. "URSI-IRE Meeting at NBS," NBS Tech. News Bulletin, Vol. 34, No. 6, p. 91, June, 1951.

ABSTRACT

This is a brief review of the URSI-IRE meeting of April 16-18, 1951, in Washington, D. C.

61. "Tropospheric Propagation Research," NBS Tech. News Bulletin, Vol. 36, No. 8, August, 1952.

ABSTRACT

The Tropospheric Propagation Research program at the Central Radio Propagation Laboratory is described in detail.

62. "NBS Boulder Laboratory," NBS Tech. News Bulletin, Vol. 36, No. 12, p. 180, December, 1952.

ABSTRACT

The new Boulder, Colorado Laboratory for the Central Radio Propagation Laboratory is described.

63. P. J. Short, J. W. Herbstreit, and P. L. Rice, "Catalog of Available Tropospheric Field Strength Data," NBS Report No. 2915, October 28, 1953; (supersedes NBS Report No. 2011, October 27, 1952).

ABSTRACT

A reference to tropospheric propagation data covering approximately 200 propagation paths for distances from 33 to 616 miles and frequencies from 41 to 24,000 Mc is presented in order to disseminate the information available at the National Bureau of Standards.

64. "NBS Research in Radio Propagation," NBS Tech. News Bulletin, Vol. 38, No. 4, p. 49, April, 1954.

ABSTRACT

This paper reviews the progress of research at the Central Radio Propagation Laboratory, which is aimed at better systems, more accurate standards, and more reliable propagation forecasts for use by the government, industry, and science.

65. "Dedication of NBS Boulder Laboratories," NBS Tech. News Bulletin, Vol. 38, No. 8, p. 122, August, 1954.

ABSTRACT

Plans for the dedication of the National Bureau of Standards Laboratories in Boulder, Colorado, are reviewed. Scientific conferences on cryogenics engineering and on radio propagation are planned for the same time.

66. "Annual Report of Central Radio Propagation Laboratory, July 1, 1951-June 30, 1952," NBS Report 1962, October 1, 1952.

67. "Annual Report of Central Radio Propagation Laboratory, July 1, 1952-June 30, 1953," NBS Report 2793, September 14, 1953.

68. "Semi-Annual Report of Central Radio Propagation Laboratory, July 1, 1952-December 31, 1952," NBS Report 2405, March 31, 1953.

69. "Semi-Annual Report of Central Radio Propagation Laboratory, January-June, 1953," NBS Report 2732, August 12, 1953.

70. "Quarterly Report of Central Radio Propagation Laboratory, January-March, 1952," NBS Report 1795, July 17, 1952.

71. "Quarterly Report of Central Radio Propagation Laboratory, April-June, 1952," NBS Report 1876, August 20, 1952.

72. "Quarterly Report of Central Radio Propagation Laboratory, July-September, 1952," NBS Report 2090, December 2, 1952.

73. "Quarterly Report of Central Radio Propagation Laboratory, July-September, 1953," NBS Report 2936, November 24, 1953.

B. Development of Theory and Prediction Methods.

(a) Propagation Parameters.

74. K. A. Norton, "A Formula for the Transmission Loss of Space Waves Propagated Over Irregular Terrain," NBS Report No. 1737, June 16, 1952.

ABSTRACT

It is shown that the effects of irregularities in the height of the terrain on space-wave intensity calculations may be adequately described in terms of the coefficients of a second-degree polynomial fitted by the method of least squares to an appropriate portion of the terrain between the transmitting and receiving sites. The mean-square residual height variation from such a polynomial provides a measure, through Rayleigh's criterion of roughness, as to the usefulness of the resulting field-strength formula. If the frequency under consideration is sufficiently low to satisfy this criterion, then the three coefficients in the second-degree polynomial fitting the terrain are found to play important roles in determining the effective heights of the transmitting and receiving antennas, and the effective curvature of the transmission path. A constant lapse of refractive index with height may be taken into account by a modification in the effective path curvature.

The utility of the formula on frequencies between 92 and 1,047 Mc is established by comparing the calculated and measured fields for a variety of terrain in the vicinity of the Cheyenne Mountain transmitting station of the NBS.

75. K. A. Norton, "Transmission Loss in Radio Propagation," NBS Report No. 2044, October 31, 1952; Proc. IRE, Vol. 41, No. 1, p. 146, January, 1953.

ABSTRACT

The utility of the concept of transmission loss in radio propagation analysis is explored. The transmission loss of a radio system is defined to be the ratio of the power radiated from the transmitting antenna to the resulting signal power available from a loss-free receiving antenna.

76. K. A. Norton, "Transmission Loss in Free Space," prepared for presentation at the 11th General Assembly of the URSI at the Hague in August, 1954.

ABSTRACT

The advantages of the concept of "transmission loss," L, in describing the characteristics of radio wave propagation have been discussed in a recent paper by the author. A brief review of this concept together with a few new definitions is given here.

77. K. A. Norton, "Dependence of the Transmission Loss in Tropospheric Propagation on the Angular Distance," prepared for presentation at the 11th General Assembly of the URSI at the Hague, August, 1954.

ABSTRACT

It is shown that the expected values of transmission loss calculated for a smooth spherical earth by means of the Bremmer-van der Pol diffraction theory and by a recent version of the Booker-Gordon scattering theory are in fair agreement with the observed transmission losses over an actual rough earth when the angular distance, θ, is used as the common parameter.

78. H. Fine, "An Effective Ground Conductivity Map for Continental United States," Proc. IRE, p. 1405, September, 1954.

ABSTRACT

The Federal Communications Commission has recently adopted a new effective ground conductivity map, presented in this paper, representing estimates on measurements made over approximately 7,000 paths throughout United States and submitted to the FCC. The CRPL had previously made a comprehensive study of effective conductivity, using paths up to 25 miles which were plotted on map overlays; from this study the typical conductivity values for 144 of the 243 subsoil types were evaluated. The resulting conductivity map was drawn freehand by the FCC, almost entirely from the map overlays supplied by CRPL. The estimation of a standard error for this effective conductivity map is not an attractive proposition because of the variable density of the measurements, but if known would greatly enhance the utility of the map.

79. K. A. Norton, "The Role of Angular Distance in Tropospheric Radio Wave Propagation," presented before the 1953 Western Electronic Convention in San Francisco.

ABSTRACT

Angular distance is defined as the angle between the ray from the transmitting antenna to its radio horizon and the ray from the receiving antenna to its radio horizon, determined in the great circle plane containing both antennas. If a linear refractive index gradient is assumed over a smooth spherical earth, the angular distance is equal to the distance between the transmitting and receiving antenna horizons divided by the effective radius of the earth. It is shown how this parameter, to a good first approximation, allows for the systematic effects of transmitting and receiving antenna heights and the effects of irregularities in the terrain.

Comment

A revised and extended version of this paper is reproduced here as Supplement XV.

(b) Propagation Mechanisms; Comparison of Theory and Experiment.

80. J. Feinstein, "Reflection of Radio Waves from Meteor Trails," CRPL Preprint, No. 50-19, February, 1950.

ABSTRACT

This is a brief discussion on a theory of N. Herlofson of meteor trails having a core of dielectric constant zero or less. Calculations proved that the effective dielectric constant varied from unity on the surface to zero on the axis of a cylinder.

81. H. E. Bussey, "Zonal Screening, A New Wave Suppressing Technique," CRPL Preprint No. 51-22, February 5, 1951; see also "Reflected Ray Suppression" Proc. IRE, Vol. 38, No. 12, p. 1453, December, 1950, and NBS Tech. News Bulletin, Vol. 36, No. 1, p. 6, January, 1952.

ABSTRACT

A method is described for greatly reducing the reception of a direct or a reflected wave. It employs a blocking screen of such a shape as to cover about half of the area of the first Fresnel zone at a place between the transmitter and the receiver. For reflected wave suppression such a screen, set on the ground, is cut in half; then, together with its image, it behaves as a full screen and if correctly placed it blocks the wave coming virtually from the transmitter. Microwave measurements are described which confirm the theory. The Fresnel diffraction pattern of a semicircular area is derived analytically.

82. W. Miller, "Effective Earth's Radius for Radio Wave Propagation Beyond the Horizon," Jour. Appl. Phys., Vol. 22, No. 1, p. 55, January, 1951.

ABSTRACT

The geometrical optical arguments underlying the equivalent earth's radius approximation are extended to non-horizontal rays. The appropriate wave equation for a non-uniform, but spherically symmetric, region is derived in a natural way. A formal solution is obtained which contains the known solutions for a uniform medium. For the non-uniform case, the solutions to the radial equation are found by a technique due to Langer.

83. A. H. LaGrone, "Volume Integration of Scattered Radio Waves, Proc. IRE, Vol. 40, No. 1, p. 54, January, 1952.

ABSTRACT

A brief discussion on the geometry and integral equation involved in the scattering theory. The general equation for radio scattering developed by Booker and Gordon is extended to a volume-integral equation, which gives the total scattered-power density at a receiver point relative to the power radiated per unit solid angle by an isotropic source. The propagation conditions assumed are stated.

84. G. Hufford, "An Integral-Equation Approach to the Problem of Wave Propagation Over an Irregular Surface," Quart. Appl. Math., Vol. 9, No. 4, p. 391, January, 1952.

ABSTRACT

Theoretical discussion of the propagation of radio waves over a surface whose radius of curvature is everywhere much larger than a wavelength assumes that a scalar wave phenomenon is involved and that a homogeneous boundary condition applies at the surface. An integral equation is derived for the attenuation function at all points on the earth's surface, and a formal solution for the field at any point above the earth is obtained. The analysis is applied to the special cases of a plane earth and a spherical earth. Agreement with the earlier work of Norton, van der Pol, Bremmer, and Fock is noted.

85. J. Feinstein, "The Role of Partial Reflections in Tropospheric Propagation Beyond the Horizon," NBS Report No. 1447, February 6, 1952; see also NBS Tech. News Bulletin, Vol. 38, No. 2, p. 17, February, 1952.

ABSTRACT

The continuous partial reflections, which must occur as a consequence of the gradient of refractive index present in the atmosphere, are evaluated on a hybrid-ray and wave theory. It is found that the inhomogeneity associated with the standard atmosphere is sufficient to account for the anomalous field strengths found far beyond the horizon. The wavelength, distance, and angular dependences associated with this reflected energy are examined and compared with observation. The extent to which the approximate methods employed may be justified on a rigorous wave basis is indicated. The mathematics of the conventional-mode treatment is examined with a view toward ascertaining the reason for its neglect of this field contribution.

86. T. J. Carroll, "Internal Reflection in the Troposphere and Propagation Well Beyond the Horizon," NBS Report No. 1416, January 22, 1952; see also Trans. IRE, PGAP-2, p. 9, March, 1952.

ABSTRACT

A simple estimate of the feeble internal reflection from the normal troposphere explains remarkably well long puzzling fields well beyond the horizon throughout the VHF and microwave spectrum. Even in the absence of ducts, the continuous decrease with height of the index of refraction under gravitational influence makes the troposphere an inhomogeneous continuously stratified medium. The effective earth's radius notion allows for the refractive effect of this inhomogeneity in calculating the diffracted field beyond the horizon, but not for internal reflections. A bilinear model for the index profile of the normal atmosphere gives modes with db/mi attenuation rates in approximate agreement with the experimental one of roughly 1/7 db/mi at 50,400 and 3,000 Mc. To a considerable extent, the internal reflection idea obviates the need for hypothesizing omnipresent atmospheric turbulence up to heights of several miles in the troposphere, a phenomenon once erroneously thought also to cause "angel" echoes on radars.

87. T. J. Carroll, "Normal Tropospheric Propagation Deep Into the Earth's Shadow; The Present Status of Suggested Explanation," Trans. IRE, PGAP-3, p. 6, August, 1952.

ABSTRACT

During the last seven years, experimental observations of field strength measured well beyond the horizon from high-power transmitters through the VHF and microwave frequency range have shown much higher fields than conventional theory had predicted in the absence of ducts. The three types of suggested explanations have been (a) scattering by omnipresent turbulence in the atmosphere; (b) wave scattering connected with earth roughness; (c) partial internal reflections from the normal stratification of the troposphere itself. No definitive judgment can yet be made concerning the relative validity of these explanations, but the physical ideas underlying each hypothesis and the claims of their protagonists as of the end of 1951 will be summarized and checked against supporting evidence in the hope of setting the stage for the conflicts of views expected to develop later in the meeting.

Independently of the explanation which ultimately wins acceptance, it seems generally agreed that these fields will have practical importance for reliable point-to-point communication at ranges larger than formerly envisaged at VHF and microwave frequencies.

88. T. J. Carroll, "Tropospheric Propagation Well Beyond the Horizon," Trans. IRE, PGAP-3, p.84, August, 1952.

ABSTRACT

Observed VHF and micro-wave fields well beyond the horizon from high-powered transmitters are attributed to partial internal reflection from the normal troposphere with its index of refraction decreasing smoothly and continuously with height. A simple estimate of such reflection from the normal troposphere gives values well beyond the

horizon of the order of magnitude of the observed average fields of frequencies throughout the VHF and microwave range. The conventional effective earth's radius correction for refraction fails to consider the tropospheric reflection effect on the field beyond the horizon. This failure is traced to the misbehavior of the linear index model at great height. Either a bilinear model for the normal troposphere with a unit index above 30,000 feet, or an exponential model which falls asymptotically to unity at great height, gives modes whose eigenvalues depend both on the index gradient and on the total index change through the atmosphere. Observations by Pickard and Stetson are believed to give strong qualitative experimental support for the importance of the total index change in a correct wave theory of weak nonoptical fields. Comparison is possible with the hypothesis of scattering from atmospheric turbulence with respect to the following: height gain, pulse-shape preservation, antenna beam width and gain observations, short-and-long term fading characteristics, divergence factor considerations, and number of arbitrary parameters involved.

89. A. H. LaGrone, "Cross Polarization of Scattered Radio Waves," Proc. IRE, ONR Contract, p. 1120, September, 1952.

ABSTRACT

The polarization of the signal reaching a receiving antenna by the scattering mechanism proposed by Booker and Gordon is investigated. Equations are presented which give the response of dipole antennas oriented horizontally, vertically, and axially, relative to a linear polarized source. The relative response of the three antennas is calculated for selected values of the scattering parameters and a comparison made with the measured response of similar antennas to a 102.9 Mc signal arriving over a path length of 147 miles.

90. J. Feinstein, "Tropospheric Propagation Beyond the Horizon," Jour. Appl. Phys., Vol. 22, p. 1292, October, 1952.

ABSTRACT

Recent calculations of the field strength of VHF waves, based on a smooth-earth diffraction theory, give results far below the observed values in the shadow region, even when refraction produced by the standard atmosphere is allowed for. But in these calculations the contribution made by partial reflections, caused by the gradient of refractive index in the atmosphere, has been neglected. A mathematical treatment which accounts for these reflections is outlined, and results deduced from it are shown graphically.

91. H. Staras, "Scattering of Electromagnetic Energy in a Randomly Inhomogeneous Atmosphere," NBS Report No. 1662, May 12, 1952; Jour. Appl. Phys., Vol. 23, No. 10, pp. 1152-1156, October, 1952.

ABSTRACT

First-order perturbation theory is used to evaluate the scattered power at a receiver due to random inhomogeneities in the propagating medium. The integral expression for this scattered power is identical with the expressions as used by Pekeris and Booker and Gordon. However, instead of a space correlation function of refractive index variations, this paper uses a time correlation function which permits formal evaluation of the time average scattered power. It is shown that for large-scale turbulence, the frequency and scattering angle dependence of the scattered energy is affected greatly by the particular time correlation function chosen.

Comment

Subsequent work by the author resulted in material presented before the American Physical Society, June 30, 1952 in Denver, Colorado, under the title, "The Effect of Scattering by a Turbulent Atmosphere on the Received Field Deep in the Shadow Region."

92. C. R. Ammerman, "VHF Propagation Beyond the Horizon," Penn State Engineer, November, 1952.

ABSTRACT

This is a short survey of theories concerning tropospheric propagation well beyond the radio horizon.

93. J. Feinstein, "The Nature of Gradient Reflections," Trans. IRE, PGAP-4, pp. 2-13, December, 1952.

ABSTRACT

For a refractive index distribution which is an analytic function of height, a development is presented which indicates that the total effect of a gradient is of the order of the effective earth radius modification of the uniform atmosphere theory. When a discontinuity in any order derivative is present, one obtains an inverse distance power law signal dependence in which the magnitude of the power is a function of the order of the derivative possessing the discontinuity.

94. H. Fine, "Some Notes on Theory of Radio Scattering in a Randomly Inhomogeneous Atmosphere," Proc. IRE, Vol. 41, p. 294, February, 1953 (Correspondence).

ABSTRACT

Booker and Gordon define an autocorrelation function of permittivity as a space correlation. Staras has proposed the use of a time correlation function and derived an expression for the average received power due to scattering, whereas Booker and Gordon considered the instantaneous power. From practical considerations it would seem that the average power is the more useful, as the instantaneous power fluctuates greatly with time. A third definition of correlation is proposed and discussed, with correlation in the time-space domain.

95. George A. Hufford, "A Note on Wave Propagation Through an Inhomogeneous Medium," NBS Report No. 1830, July 28, 1952; see also Jour. Appl. Phys., Vol. 24, p. 268, March, 1953.

ABSTRACT

A few formal observations are made concerning wave propagation through an inhomogeneous medium. A modification of Kirchoff's formula is suggested and an integral equation derived which gives an estimate of the error made in the usual approximate methods. Applications are indicated to the equivalent earth's radius model and to the flat earth, modified index model.

96. A. P. Barsis, "Comparison of Calculated and Measured Fields Within the Radio Horizon for the 92 and 1000 Mc Range," presented at the Symposium on Tropospheric Wave Propagation within the Horizon at US NEL, San Diego, California, March 30 - April 1, 1953.

ABSTRACT

Propagation characteristics of space waves transmitted over irregular terrain may be computed by replacing significant portions of the terrain by a smooth surface, determining the fields by the usual methods applicable to smooth surfaces. The deviation of measured fields over rough terrain from computed smooth-earth values is investigated as a function of Rayleigh's criterion of roughness. Evaluation of measurements available from the Cheyenne Mountain Experiment suggests development of a formula correcting deviations of measured from computed values of transmission loss with corresponding values of Rayleigh's criterion of roughness.

Comment

This report is reproduced here as Supplement XI.

97. J. W. Herbstreit, K. A. Norton, P. L. Rice, and G. E. Schafer, "Radio Wave Scattering in Tropospheric Propagation," NBS Report No. 2459; 1953 Convention Record of the IRE, Part 2, Antennas and Communications, pp. 85-91.

ABSTRACT

The scattering theory of Booker and Gordon has been developed, assuming the correlation function $C(r) = C(0) \exp(-r/\ell)$, so as to be suitable for easy numerical calculation of the transmission loss expected with this mode of transmission; $C(0)$ denotes the time variance of the refractice index of the atmosphere, and ℓ denotes the scale of turbulence.

98. W. G. Albright and R. N. Ghose, "VHF Field Intensities in the Diffraction Zone," Trans. IRE, Vol. AP-2, p. 35, January, 1954.

ABSTRACT

A solution of the general wave equation is obtained assuming a refractive-index versus height variation of exponential form which fits the required boundary conditions. An expression for field strength as a function of the height and the separation of transmitting and receiving antennas is derived. Calculated values of signal strength are compared with measured values.

99. H. Staras, "The Statistics of Scattered Radiation," presented at the National Bureau of Standards Boulder Laboratories Dedication Program, September 8-14, 1954.

ABSTRACT

By means of a reformulation of the integrals that appear in scattering theory, this paper derives explicit mathematical expressions for many of the statistical parameters that appear in scattering theory, assuming isotropic turbulence. Among the statistical properties discussed are the statistical distribution of the received signal, the correlation of signals received on spaced antennas, and the correlation of signals as a function of the separation of the carrier frequencies.

Comment

See Report No. 100 in this list.

100. H. Staras, "A Mathematical Study of Beyond-the-Horizon Scatter Transmissions," thesis submitted to the Physics Department of the University of Maryland in partial fulfilment of the requirements for the Ph. D. degree, September, 1954.

ABSTRACT

In the past decade or so, it has been observed that the frequency band between 50 Mc and 3,000 Mc, approximately, could be used fairly reliably for long distance communication (i.e., when the transmitter and receiver are well beyond each other's radio horizon). The dominant characteristics of these long-distance signals is their high signal strength (as compared with any previously known theory) and their severe fading. Because of these characteristics, a scattering mechanism was postulated. Booker and Gordon, using an approach originally developed by Pekeris, were the first to develop an appropriate mathematical approach for scattering of radio waves by random inhomogeneities in the troposphere.

It is the purpose of this thesis to extend their work by deriving appropriate formulas for the statistical properties of the scattered radiation in terms of the four-dimensional autocorrelation function of the random inhomogeneities in the troposphere. Both isotropic and anisotropic turbulence are considered.

(c) Statistical Methods

101. K. A. Norton, Edna L. Schulz, and Helen Yarborough, "The Probability Distribution of the Phase of the Resultant Vector Sum of a Constant Vector Plus a Rayleigh Distributed Vector," Jour. Appl. Phys., Vol. 23, No. 1, pp. 137-141, January, 1952.

ABSTRACT

Formulas, tables, and graphs are given of the cumulative probability distribution of a function frequently occurring in the theory and practice of radio wave propagation as well as in the study of the influence of noise in modulation studies.

102. K. A. Norton, H. Staras, and M. Blum, "A Statistical Approach to the Problem of Multiple Radio Interference to FM and Television Service," Trans. IRE PGAP-1, pp. 43-49, February, 1952.

ABSTRACT

This paper presents a statistical analysis of the problem of FM and television service in the presence of multiple sources of interference, assuming that the received fields vary in time and space as described in the FCC Ad Hoc Committee report and its references C, D, and E. It is believed that comparisons of national services which differ because of different allocation policies maybe made with a sufficiently high degree of accuracy to warrant the use of the methods developed in this paper.

103. P. L. Rice "A Comparison of Methods for Evaluating Trends in Time Series of Tropospheric Radio Field Strength Data," NBS Report No. 1742; Trans. IRE PGAP-3, p. 144, August, 1952.

ABSTRACT

This paper presents a short review of several methods for evaluating the "seasonal trend" in a series of hourly median field strengths corresponding to one hour of the day. Two tools of the statistician, the autocorrelation function and the variate difference method, refine the analysis of time trends to a point where a maximum amount of correlation with relevant meteorological data is hoped for.

104. H. Staras, "Trend Analysis and Prediction in a Discrete Gaussian Stationary Process," in preparation (presented at a Bureau of Standards symposium in August, 1953).

ABSTRACT

Under the assumption that a discrete time series represents a Gaussian stationary process, this paper derives the maximum likelihood estimate for the "trend" when no functional form for the trend is known. In addition, this paper obtains the probability distribution associated with a future occurrence.

Comment

This paper is reproduced here as Supplement XIII.

105. J. Feinstein, "Some Stochastic Problems in Wave Propagation," Trans, IRE, Vol. AP-2, Part I, No. 1, p. 23, January, 1954.

ABSTRACT

The effect of random height variations associated with a conducting surface upon the characteristics of reflected wave energy is ascertained by the methods of physical optics. Average received power, its variance, angular frequency power spectra, and the field correlation pattern are determined in terms of the statistical parameters of the surface. The results are applied to various problems encountered in tropospheric and ionospheric wave propagation.

106. J. Feinstein, "Some Stochastic Problems in Wave Propagation - Part 2," Trans. IRE, Vol. AP--2, No. 2, April, 1954.

ABSTRACT

In Part I some of the properties of wave energy reflected from surfaces subject to random height variations were investigated.

Here we ascertain the effects of refractive index fluctuations within a volume upon the properties of waves traversing the medium. The results are applied to problems encountered in tropospheric and ionospheric propagation.

107. J. Feinstein, "Some Information Theory Aspects of Propagation through Time Varying Media," 1954 IRE Convention Record, Part 2, Antennas and Communications, p. 87.

ABSTRACT

The channel capacity of a communications system which utilizes wave propagation through a time varying medium such as the ionosphere or troposphere is evaluated in terms of the statistical properties of the medium and of the noise. The signal fading in such a system reduces the capacity.

Information theory concepts are broadened to include the possibility of multiple reception at spaced receiving sites, and the consequent increase in theoretical channel capacity is computed as a function of the number of such sites. Current practices in the use of diversity reception and directional antennas are examined in the light of these results.

108. K. A. Norton, P. J. Short, and W. Mansfield, "The Cumulative Probability Distribution of the Instantaneous Resultant Amplitude of the Vector Sum of a Constant Component and a Randomly Phased Rayleigh Distributed Vector

Component," prepared for presentation at the 11th General Assembly of the URSI at the Hague, August, 1954.

ABSTRACT

In this paper somewhat more accurate distributions than those formerly available are derived for the case where one component of a received field is large compared to the remaining components. The median value and fading range (interdecile range) of a signal composed of a Rayleigh distributed component adding in random phase with a constant component are shown as functions of the ratio between the power in the constant component and the average power of the Rayleigh component.

Comment

This report is reproduced here as Supplement XVI.

109. G. McCrossen, "Long-Term Theoretical Cumulative Distribution Function for Tropospherically Scattered Fields," in preparation.

ABSTRACT

In the analysis of radio transmission loss data it has been convenient to tabulate data in the form of hourly median values of transmission loss and to separately analyze characteristics of the data within each hour. Defining x to be the amplitude in volts of an instantaneous signal, it is desirable to obtain a reasonable approximating cumulative distribution function of x over an indefinitely long period of time. It is the intent of this note to derive, under certain restrictive conditions, such a cumulative distribution function and to indicate how it can be evaluated to any prescribed degree of accuracy.

(d) Estimating VHF, UHF, and Radar Coverage or Service Range.

110. K. A. Norton and A. C. Omberg, "The Maximum Range of a Radar Set," Proc. IRE, Vol. 35, No. 1, p. 4, January, 1947.

ABSTRACT

Formulas are derived which may be used to calculate the maximum range of a radar set. It is shown that the maximum range obtainable with a given radar set depends upon (1) the energy in the pulse, i.e., the peak power times the time duration of the pulse or the average power divided by the pulse-recurrence frequency; (2) the transmitting and receiving antenna gains; (3) the transmission line, antenna, and transmit-receive-box losses; (4) the "effective width" or time duration of the transmitted pulses; (5) the "effective bandwidth" of the receiver; (6) the radio frequency of the transmitted waves; (7) the recurrence frequency for the transmitted pulses; (8) the "noise figure" of the receiver; (9) the cosmic, atmospheric, and man-made noise picked up by the antenna; (10) the attenuation during passage of the radio waves through the atmosphere due to the absorption by the atmospheric gases and rain drops; (11) the "effective echoing area" of the target; (12) the directivity of the transmitting and receiving antennas in elevation and azimuth; and (13) the effect of the ground, which, in turn, is inextricably associated with the particular site used, the height of the target above the ground, and the polarization of the transmitted radio waves.

111. K. A. Norton and H. Fine, "A Study of Methods for the Efficient Allocation of Radio Frequencies to Broadcasting Services Operating in the Range Above 50 Mc," CRPL Report 4-5, August 1, 1949.

ABSTRACT

Methods are developed for describing the service provided by a television broadcasting system. It is shown how the service range of a clear channel television broadcasting station is limited by receiver and cosmic radio noise and

formulas are presented for determining the field strength required to provide a satisfactory television service in this case.

112. H. Staras, "The Effect on Television Service of Transmitting Antenna Height, Radiated Power, the Use of Off-Set or Synchronized Co-Channel Carriers, and of Correlation Among the Radio Fields Received from Several Transmitters," CRPL Report 6-1, October 10, 1949.

ABSTRACT

Calculations have been made which provide useful information for consideration in the efficient allocation of frequencies to television stations. These calculations show that: (1) increasing, for all stations, either the transmitting antenna height or the effective radiated power or both, substantially improves the total service which can be provided, particularly in those regions where service is provided by only one or two stations; (2) synchronizing or "off-setting" co-channel carriers almost doubles the efficiency of service which can be provided to stations allocated in a triangular lattice network; and (3) the assumption of no correlation among the desired and undesired fields leads to results concerning efficiency of service which are quite accurate.

113. K. A. Norton and L. Gainen, "A Study of the Influence of the Geographical Distribution of Population on The Coverage Obtainable from a National Television System," a working document to the FCC Ad Hoc Committee for the Evaluation of FM and TV Propagation Factors Between 50 and 250 Mc, October 27, 1950.

ABSTRACT

In the present paper some studies are made, in the light of the actual distribution of the population in the Washington-Baltimore area as determined by the 1940 census, of the degree to which maximizing area of coverage is equivalent

to maximizing the number of people provided with satisfactory service. Having in mind that the radio field strength required for a satisfactory television service is likely to depend upon the density of the population in the neighborhood of the receiving location, this study is based upon a definition of satisfactory service involving required field strengths which vary with population density.

114. K. A. Norton, "Addendum to Reference E," a working document of the FCC Ad Hoc Committee for the Evaluation of FM and TV Propagation Factors Between 50 and 250 Mc, November 16, 1950.

ABSTRACT

This addendum brings the analysis in Reference E to the Ad Hoc Committee Report up to date and extends it in several directions. It is emphasized that soundly conceived definitions of service are basic to the development of a proper allocation, and the point is made that the FCC definition of three "grades" of television service appears to be defective. Optimum methods of television station allocation are described based on these alternatives: (a) maximizing the coverage of area per station; (b) maximizing the coverage of area per channel; or (c) maximizing the coverage of people.

115. R. S. Kirby, J. W. Herbstreit, and K. A. Norton, "Service Range for Air-to-Ground and Air-to-Air Communications at Frequencies Above 50 Mc," Proc. IRE, Vol. 40, No. 5, p. 525, May, 1952.

ABSTRACT

Propagation aspects of air-to-ground and air-to-air communications are analyzed. Contours of constant received signal strength are shown in the form of lobes for various frequencies. It is shown that for systems with

equivalent transmitted power, ground antenna height, and transmitting and receiving antenna gain the service range decreases as the frequency is increased. This is due primarily to a decrease in the absorbing area of the receiving antenna and to a larger number of nulls in the lobe structure arising from interference between direct and ground-reflected waves. Ground station antenna height diversity and tilted-array ground antenna systems are discussed as a means of improving coverage as the operating frequency is increased.

(e) Radio Meteorology.

116. G. Birnbaum, "Millimeter Wavelength Dispersion of Water Vapor," NBS Report No. 1943, September 23, 1952; see also Journ. Chem. Phys., p. 57, January, 1953.

ABSTRACT

Dispersion due to water vapor in the wavelength region from infinity to 0.6 mm is computed by means of quantum mechanical formulas. The dispersion is attributed to: (1) the contributions of the 11 rotational lines in the region considered; these are obtained with a dispersion equation characteristic of collision theory specialized to sharp lines; and (2) the combined contribution of all rotational lines of shorter resonance wavelength. This is obtained with the aid of the well-known shape factor $(\nu_n^2 - \nu^2)^{-1}$, which is shown to be valid for sharp lines independent of any special model.

117. E. K. Smith, Jr. and Stanley Weintraub, "The Constants of the Equation for Atmospheric Refractive Index at Radio Frequencies," NBS Report No. 1938, September 19, 1953; Proc. IRE, Vol. 41, No. 8, pp. 1035-1037, August, 1953.

ABSTRACT

Recent improvements in microwave techniques have resulted in precise measurements at the National Bureau of Standards, the National Physical Laboratory, and

elsewhere which indicate that the conventional constants in the expression for the refractivity of air should be revised. In much of propagation work, the absolute value of the refractive index of the atmosphere is of small moment. However, in some work it is important, and it seems highly desirable to decide upon a particular set of constants. Through consideration of the various recent experiments, this paper arrives at a relation

$$N = (n-1)\,10^6 = \frac{77.6}{T}\left(p + \frac{4810\,e}{T}\right),$$

Where

N = refractivity of air
n = refractive index of air
T = absolute temperature in degrees Kelvin
p = total pressure in millibars
e = partial pressure of water vapor in millibars

This expression is considered to be good to 0.5 per cent in N for frequencies up to 30,000 Mc and normally encountered ranges of termperature, pressure, and humidity.

C. Use of Theory and Prediction Methods to Solve Specific Problems.

(a) Air-to-Ground Communications.

118. J. W. Herbstreit and Harold Staras, "The Effect of Interference from a Co-Channel Station on Double Channel Air-to-Ground Communication, A Preliminary Study," RTCA Paper 38-51/DO-31, March 26, 1951, (appendix), entitled "Communication Frequencies Required within the Band 118.1 -126.7 Mc, during the Period 1951-1953 Inclusive and Recommended Implementation Thereof."

ABSTRACT

An estimate is made of the required separation between ground stations and the required ground antenna height necessary to provide various grades of service when taking

into account co-channel interference from one other ground station. An evaluation of air-to-air interference encountered in Single Channel Simplex and Double Channel Simplex operation has also been made.

119. H. Staras, P. L. Rice, and J. W. Herbstreit, "An Analysis of Propagation Phenomena as Affecting VOR Communication Systems," NBS Report No. 1038, June 19, 1951.

ABSTRACT

Graphs are presented giving the service to be expected in the presence of interference from co-channel stations of standard and short range VOR radio navigation facilities. These graphs take into account the fluctuations of the received field due to inhomogeneities in the atmosphere, irregularities of the terrain, and the random variation of directivity associated with aircraft antenna patterns. Tables are given of service range under various separations of co-channel stations and altitudes of aircraft for two different grades of reliability of service.

120. K. A. Norton and P. L. Rice, "Gapless Coverage in Air-to-Ground Communications at Frequencies Above 50 Mc," Proc. IRE, Vol. 40, No. 4, p. 470, April, 1952.

ABSTRACT

It is shown that there is an optimum ground station antenna height for use in typical air-to-ground communications systems. When antennas lower than this optimum are used, the maximum distance range is reduced at all aircraft altitudes. When antennas higher than this optimum are used, the interference between the direct and ground-reflected waves causes gaps to occur in the coverage at the higher aircraft altitudes. The minimum altitude at which the gap in coverage occurs decreases with increasing frequency and with increasing ground station antenna height. The optimum antenna height decreases with increasing frequency, and this, in turn, reduces the maximum distance range for satisfactory communication as the frequency

increases. The curves presented are based on values expected from theory for a smooth spherical earth. Such curves have been found experimentally to approximate very well the average practical operating results.

121. P. L. Rice, W. V. Mansfield, J. W. Herbstreit, "Ground-to-Air Co-Channel Interference at 2900 Mc," NBS Report No. 1909, Trans. IRE PGAE-6, December, 1952.

ABSTRACT

Estimates are given of average ground-to-air interference for a ground installation utilizing a Bendix ASR-1 vertically polarized antenna operating at 2900 Mc. Coverage is defined in terms of 0, 6, 12, and 18 db protection ratios with respect to a similar installation sending out a desired signal, with station separations of 10, 50, 100, and 150 miles being considered. "Coverage" here is not synonymous with the usual concept of service, for no minimum signal is taken into account, but only the ratio between desired and undesired field strengths. Limitations of the estimates are discussed, and their derivation is explained in an appendix to the report.

(b) Point-to-Point Communications.

122. M. Blum and P. L. Rice, "Tropospheric Propagation Charts for 30, 400, and 600 Megacycles," NBS Report No. 1007, May 10, 1951.

ABSTRACT

Propagation charts are given showing the time distribution of received radio field strengths as a function of distance for various frequencies and transmitting antenna heights, assuming a receiving antenna height of 30 feet. The charts were computed by an extrapolation of the methods and formulas derived by the FCC Ad Hoc Committee for frequencies from 50 to 250 Mc.

123. J. W. Herbstreit, "Propagation in the UHF-TV Band," IRE, Convention Record, p. 120 (abstract), 1954.

ABSTRACT

The Central Radio Propagation Laboratory of the National Bureau of Standards has been conducting a program of research at frequencies of 418 and 1046 Mc in conjunction with an extensive 100 and 200 Mc program of measurements throughout the United States. Reception of 1046 Mc transmissions 400 miles from Cheyenne Mountain, Colorado has been found possible at all times. By far the most important factor determining the available signal power in the UHF band is the effective absorbing area of the receiving antennas. An estimate of expected service and interference ranges at VHF and at UHF is included in the talk.

Comment

A written version of this talk presented before the 1954 IRE National Convention is included as Supplement XVIII to this paper.

124. K. A. Norton, "Point-to-Point Radio Relaying via the Scattering Mode of Tropospheric Propagation," prepared for presentation at the 11th General Assembly of the URSI at the Hague, August, 1954.

ABSTRACT

Experimental data on the transmission loss far beyond the radio horizon in the frequency range 100 to 1000 Mc are extrapolated by means of the Booker-Gordon scattering theory to transmission frequencies as high as 50,000 Mc. Similarly, data and theories of the expected atmospheric absorption presented by Bussey for relatively short paths are extrapolated to longer distance paths. These extrapolations provide estimates of the feasibility of point-to-point radio relays in the frequency range 100 to 50,000 Mc over distances ranging from 100 to 500 miles of the following types of service:

60 words per minute frequency shift telegraphy, frequency modulated voice, frequency modulated high fidelity music, and U. S. standard television transmissions.

Comment

This report is reproduced here as Supplement XVII.

D. Description of Equipment and Equipment Standards.

(a) Measurement of Field Strength.

125. F. M. Greene and M. Solow, "Development of VHF Field Intensity Standards," NBS Journ. Res., Vol. 44, No. 5, p. 527, May, 1950.

ABSTRACT

In many instances the accuracy with which the value of a physical quantity may be determined increases with the simplicity of the method used to make the determination. Such methods usually involve a theoretical calculation, or an experimental observation, or both. In establishing the "standard-antenna method" and the "standard-field method" discussed herein, the methods were purposely made as elementary as possible for this reason. It is believed that this enables the achievement of the maximum accuracy possible or practicable at the present time between 30 and 300 Mc.

126. F. M. Greene, "The Influence of the Ground on the Calibration and Use of VHF Field-Intensity Meters," Proc. IRE, Vol. 38, No. 6, p. 650, June, 1950.

ABSTRACT

VHF field strength measurements will be generally in error if either the receiving antenna height or ground constants are appreciably different from those existing when the field-intensity meter was calibrated. These errors are discussed.

127. F. M. Greene, "Calibration of Commercial Field-Strength Meters at the National Bureau of Standards," NBS Report No. 1019, July 11, 1951.

ABSTRACT

A brief description is given of the standards and methods used in the calibration of commercial radio field strength meters at the National Bureau of Standards in the frequency range 10 kc to 300 Mc. A calibration consists in part of measuring the overall linearity of the field strength meter at one or more frequencies and r-f input voltage levels, and of measuring the internal attenuator ratios at one or more frequencies in terms of precision dissipative type step attenuators as well as precision mutual inductance attenuators, depending on the frequency being used. The remainder of the calibration consists of determining the so-called antenna coefficient or correlation factor of the set relating field strength to the output meter reading. Below about 30 Mc this is done only for sets using loop antennas in terms of a quasi-static magnetic field produced by a single-turn balanced transmitting loop. Above this frequency for sets using only dipole antennas, a locally generated radiation field is used and is evaluated in terms of the e.m.f. induced in a horizontal receiving dipole. The accuracies of the various parts of the calibration are discussed for different portions of the above frequency range.

(b) Refractive Index Measurement and Computation.

128. G. Birnbaum, "A Recording Microwave Refractometer," Rev. Sci. Instr., Vol. 21, No. 2, pp. 169-176, February, 1950; see also NBS Tech. News Bulletin, Vol. 34, No. 4, p.45, April, 1950.

ABSTRACT

An instrument designed to measure and record a small difference between two cavity resonators is described. A sweep frequency technique is used to generate the resonance

responses of the cavities. These responses are sharpened and made to control the operating time of a trigger circuit, whose average output is metered. Applications of the instrument are discussed, especially those relating to measuring changes in dielectric constant. A simple extension of the present instrument is suggested for simultaneously recording changes in dielectric constant and loss.

129. S. Weintraub, "Slide Rule for the Computation of the Refractive Index of Air," NBS Report No. 2180, November 5, 1952; see also "Slide Rule Computes Radio Refractive Index of Air," Electronics, January, 1953.

ABSTRACT

A slide rule method has been developed for the computation of the radio refractive index of moist air from temperature, pressure, and humidity data. The method attains good precision with relative ease of calculation. It makes use of two easily constructed slide rules.

130. W. E. Johnson, "An Analogue Computer for the Solution of the Radio Refractive Index Equation," NBS Report No. 2703, July 20, 1953; see also NBS Journal of Research, Vol. 51, No. 6, p. 335, December, 1953.

ABSTRACT

The solution to the radio refractive index equation provides information necessary to the research worker studying tropospheric radio propagation in the VHF and UHF regions. An analogue computer has been developed to solve this equation:

$$N = (n - 1)10^6 = \frac{77.6}{T} \left(p + \frac{4810\, e}{T}\right)$$

where

N = refractivity of air
n = refractive index of air
T = absolute temperature in degrees Kelvin
p = total pressure in millibars
e = partial pressure of water vapor in millibars.

A unique feature of this computer is the modification of a linear ten-turn potentiometer so that its output to input voltage ratio versus rotation closely approximates the exponential type curve of the saturated water vapor term in the refractive index equation.

Comment

This computer is now in use at the Central Radio Propagation Laboratory of the National Bureau of Standards and has superseded other methods of calculating the radio refractive index.

(c) General.

131. J. W. Herbstreit, "Extension of Signal Generator Voltage Range to Lower Output Levels," NBS Report No. 1934, September 11, 1952; see also "Signal Generator for Low Output Levels," Electronics, Vol. 26, p. 218, January, 1953.

ABSTRACT

With narrow-band, crystal-controlled receivers in the frequency range from 92 to 1047 Mc, useful measurements have been made of available received signal energy at 170 db below one watt, corresponding to a 50-ohm signal generator output level of only 0.022 microvolts. With a heterodyning system using two standard signal generators and a crystal mizer, leakage fields from the signal generators are effectively eliminated.

132. C. R. Ammerman and R. L. Riddle, "Low-Frequency Modulator for Receiver Testing," Electronics, Vol. 25, No. 9,pp. 240, 244, 248, September, 1952.

ABSTRACT

Modulation of signal generators at frequencies in the order of 1 cycle is usually not feasible by ordinary methods.

A resonant circuit tuned at the modulating rate by a variable-speed motor is suggested, and the drawing of a resonator suitable for use at VHF is included.

133. W. E. Johnson, "Semi-Logarithmic Rectangular Coordinate Recorder," NBS Report No. 2288, February 6, 1953.

ABSTRACT

A new recorder consisting of two separate amplifying and displacement systems uses standard 11 by 16 inch graph paper in true rectangular coordinates and is controlled by the amplitude and phase of an audio signal.

E. Subcontractors' Progress Reports
(Some of these reports predate the Signal Corps contract which later supported the work.)

(a) Collins Radio Company

134. Report No. 1, November 3, 1949.

This contract No. CST-10783 with the CRPL of NBS, deals with the measurement and recording of field strengths at five different antenna heights, up to 500 feet, a frequency of 410 Mc over a non-optical path of about 100 miles, to be performed near Cedar Rapids, Iowa. Much equipment to be used on this project will be loaned to this company by the NBS.

This report covers activities previous to the 3rd of November, 1949, when measurements were made from the 27th of October to the 3rd of November at a receiving site near Waukon, Iowa. Subjects discussed in this report are the following:

(a) Purpose of project.
(b) Scope of project.
(c) Summary of work done, (very detailed), including data in tabulated form in decibels above 1μv/m/kw for six days.

(d) Results of measurements, (variations of field strengths, 18 graphs).
(e) Plans for future operations, (equipment, receiving site).

135. Report No. 2, December 1, 1949. (Author: S. C. Shallon, Project Engineer)

This report covers activities during the period of the 4th to the 30th of November, 1949. Some propagation runs were made, from the 16th to the 23rd of November, using a directional transmitting antenna beamed on the receiving station at the WHO tower near Mitchellville, Iowa.

An explanation is given of the method used in analyzing the eight days of recorded field strength signals, their conversion into tabulated data form, the 17 graphs for percentage of time, and the final distribution curve. A correlation is attempted with weather conditions.

In anticipation of future installation of a 50-channel time-totalizer, 50 Veeder-Root counters and their synchronous drive motors were placed on a 24-inch square panel to facilitate the simultaneous photographing of all fifty counters once each hour. Six 10-channel time-totalizer chasses are being constructed, one is a spare.

Explorations for a new receiver site will be necessary during the next report period, due to the present modification plans at station WHO, to change the transmitting antenna.

136. Report No. 3, January 1, 1950. (Author: S. C. Shallon, Project Engineer.)

This report covers the month of December, 1949, in which two propagation runs were made, from the 5th to the 13th, and from the 16th to the 21st of December, using a directional transmitting antenna at the Cedar Rapids Municipal Airport beamed on the receiving station at the base of the WHO tower near Mitchellville, Iowa.

Improved equipment allowed most of the data to be analyzed by photographic time-totalizer records. The schedule of tables and curves to be submitted each month on the data is the following:

A. Tables:
   (1) Field strength in decibel units.
   (2) Percentage of time the signal exceeds chosen decibel levels.
   (3) Hourly summary of field strengths.

B. Graphs:
   (1) One graph on the 1%, 50%, 90%, 99% of time the signal exceeded a decibel level for the month.
   (2) Percentage of time the signal exceeded a decibel for each hour of each propagation run.
   (3) Diurnal variation at 1%, 50%, 90%, and 99% of the time.

The first chassis for the 10-channel time-totalizer was completed and placed in operation on the 16th of December. The frequency converter was completed and tested. Photographs and a circuit diagram of the time -totalizer are included in this report.

Station WTAD-FM, 99.5 Mc, Quincy, Illinois, has an antenna tower which is 750 feet high; this will be investigated as a possible new location for the recording antennas of this project.

137. Report No. 4, February 1, 1950. (Author: E. N. Phillips, Project Engineer.)

This report covers the month of January, 1950, in which two propagation runs were made: from the 6th - 12th, and from the 23rd - 30th of January. The same equipment and techniques were used as last month. The data is presented as outlined in Report No. 3.

S. C. Shallon of Collins Radio Company, and G. R. Chambers of CRPL, visited and conferred with the management of station WTAD-FM, Quincy, Illinois, with favorable results, concerning use of their site and facilities for the recording receiver to be removed from station WHO-FM.

138. Report No. 5, March 1, 1950.

Using the same facilities as mentioned in preceding reports, two propagation runs were made this month, from February 6 - 12 and 20 - 26, inclusive.

Five additional 10-channel time-totalizer chasses were completed and tested, some persistent tube repair was necessary, and modification of the receiver was begun this month.

A thorough discussion is given in this report on the equation upon which the data conversion is accomplished. The scheduled tables and curves of the data are presented.

139. Report No. 6, April 1, 1950.

One propagation run was made during this period at the WHO site, from March 6 - 12, using the same facilities and techniques mentioned in previous reports. The scheduled appropriate tables and curves are presented, and other graphs of a summation comparison nature, as:

(a) A distribution curve of field strength for March as compared with curves from previous reports on November, December, 1949, and January, February, 1950.

(b) A family of graphs (12) are submitted on data accumulated during the five months at this WHO location.

(c) A graph on summation average of diurnal variation.

A test run was conducted at the site of the WTAD-FM tower near Quincy, Illinois, from the 21st - 23rd of March, 1950, to assess the suitability of the site for the relocation of the receiver. Four members of this project, with adequate equipment, went to Quincy on March 21 to start operations. The received signal amplitude was great enough to choose this site as a receiving terminal in the future. If this permanent site at WTAD-FM does not give suitable signals, it is planned to use portable equipment to measure signal levels at different sites along the path from Quincy to Cedar Rapids.

140. Report No. 7, May 1, 1950.

Two propagation runs were made during April, from the 10th - 17th and from the 24th - 30th, inclusive, at the WTAD-FM tower site. The same equipment and techniques were used as those previously, but only the recording from the 14th to the 17th was used in this report. The scheduled conversion and curves are submitted.

A detailed description is given on the present modification of the resnatron transmitter.

141. Report No. 8, June 1, 1950.

This is the concluding report of the series, covering May, 1950. Using the same facilities as mentioned in report No. 7, two propagation runs were made, from May 11 - 17, and from 22 - 28, inclusive. The treatment of these data is performed in the same manner as described in report No. 2; the usual tables and curves of the data are presented.

The present location at the site of the WTAD-FM transmitting tower near Quincy, Illinois, has proved to be satisfactory.

(b) Federal Communications Commission.

142. FCC Report No. 1, May 15, 1951. (Author: E. W. Allen, Project Director.)

This report covers the period from March 1 through April 30, 1951, although preliminary work of setting up equipment began about February 16, 1951.

Log sheets of transmitter schedules will be submitted by the transmitting stations each month to report any malfunctioning of equipment. The following is a list of the recording sites, by state, and the number of stations monitored by each.

a. California.	
Livermore	3 stations
Santa Ana	3 stations
b. Florida.	
Fort Lauderdale	1 station
c. Georgia.	
Powder Springs	3 stations
d. Massachusetts.	
Millis	3 stations
e. Maryland.	
Laurel	4 stations
f. Michigan.	
Allegan	3 stations
g. Nebraska.	
Grand Island	3 stations
h. Texas.	
Houston	1 station

143. FCC Report No. 2, July 13, 1951. (Author: W. C. Boese, Acting Project Engineer.)

All of the recording sites listed in Report No. 1 were in use between May 1 and June 30, 1953, except three;

a total of 58 Esterline-Angus chart rolls was fowarded this month to the CRPL group in Washington to be scaled by CRPL personnel.

The FCC Laboratory Division made calibration checks on recording installations in Michigan and Maryland; enclosed is a table of antenna factors.

144. FCC Report No. 3, July 1 through October 31, 1951.

Since July 1, 1951, the recorder charts have been analyzed by the FCC Field Engineering and Monitoring Division, usually at the recording sites. Tabulated sheets for 49 months of analyzed data on 18 stations were forwarded to CRPL in Washington at the same time as 39 chart rolls were sent to be analyzed by CRPL personnel. An explanation is given in this report of a new method of analyzing very low signal strengths on charts; instead of hourly medians being obtained, the number of minutes during the hour that the signal exceeds certain predetermined levels is recorded. Included in this report are lists of transmitter and path characteristics for 26 monitored stations and fifteen different receiver calibrations, giving the recommended antenna factors.

145. FCC Report No. 4, July 10, 1952. (Author: G. E. West, Acting Chief, TID.)

Three cumulative distributions are presented in this report for data from July through December, 1951, hours from 1900 to 2200, on 45 FM stations and 7 TV stations. On February 11, 1952, 42 tabulated data sheets and 84 transmitter schedules on 19 monitored stations were sent to the relocated CRPL in Boulder, Colorado.

146. FCC Report No. 5, July 16, 1952.

Ten new antenna calibration factors are given in this report; 53 transmitter schedules and 60 tabulated data sheets were sent to CRPL in Boulder, Colorado. February 11, 1952, George Waldo, Project Engineer for the CRPL-FCC recording program, visited CRPL, and discussions were held on equipment, methods of analysis, and future plans for this project.

147. FCC Report No. 6, April 1 through June 30, 1952. (Author: G. V. Waldo.)

This report covers data accumulated during April, May, and June, 1952. Experiments are described which were conducted at Livermore, California and at Laurel, Maryland on the effects of terrain variations in regularly monitored field strengths as compared with such variations affecting fields from local transmitters.

A general review of the recordings from each monitoring station is presented for all paths monitored during the fiscal year ending June 30, 1952, and a table of transmitting antenna heights is included.

148. FCC Report No. 7, July 1 through September 30, 1952.

This report describes the operation of recording facilities at each of the recording sites used by the FCC. In accordance with the plans outlined in the proposal to CRPL on June 5, 1952, a number of changes were made in the installations at the recording sites before starting to record the new paths listed in the proposal. A list is given in this report showing the status of recordings at each monitoring station.

(On January 5, 1953, 80 tabulated sheets of data for 26 stations were mailed to CRPL.)

149. FCC Report No. 8, October 1 through December 31, 1952.

A complete list is given showing the status of the recordings at each of the monitoring stations for the last quarter of 1952. (On March 6, 1953, 63 data sheets were mailed to CRPL. Each such sheet covers a recording period of one month for one station.)

A list is given of 34 propagation paths for which terrain profile charts are being completed by the FCC.

150. FCC Report No. 9, January 1 through March 31, 1953.

A status list is given of all stations recorded during January, February, and March. On February 12, an inspection was made of technical facilities at the KMAR transmitter, Bakersfield, California; there were indications that the transmitter and antenna systems were not up to par.

(May 21, 1953, data sheets for 21 paths were sent to CRPL in Boulder.)

A complete description is given of a special mobile field strength survey of three Fresno, California stations, and three cumulative distribution curves are plotted.

151. FCC Report No. 10, April 1 to June 30, 1953.

This is the concluding report for the project, and describes the operation of recording installations during April, May, and June, 1953; this is a list including the receivers used and the dates of termination of recordings. Also included are lists of geographical coordinates of recording installations and a summary list of receiver antenna factors for all antennas used in the project.

A detailed description is given of the effects of averaging and sampling techniques in the measurement of rapidly fading signals.

(c) United Broadcasting Company.

152. UBC Report No. 1, March, 1950.

Quite a detailed description is given in this report of the necessary preliminary preparation of equipment needed for the project. Of 29 available stations, the following were selected for monitoring:

a. WHKC-FM, vertical and horizontal receiving antennas.
b. WCOL-FM
c. WVKO-FM
d. WXYZ-TV

153. UBC Report No. 2, April, 1950.

Charts were analyzed and hourly medians tabulated for WVKO-FM, WHKC-FM, and WCOL-FM, all located in Columbus, Ohio, and recorded at Hudson, Ohio. Problems reported on include measurement of noise figures, air temperature control, building antenna supports, adjusting recorder chart speeds and time constants to accommodate rapid signal fading.

154. UBC Report No. 3, May, 1950.

The construction of a helix antenna to measure circularly polarized fields from WHKC-FM is described. Data are tabulated and a new setup to monitor WJR-FM is reported.

155. UBC Report No. 4, June, 1950.

Data for five recording channels are tabulated. A summary of the progress of the project is included in the report.

156. UBC Report No. 5, July, 1950.

Data for July are tabulated; general information about equipment breakdowns and remeasurement of noise figures is reported.

157. UBC Report No. 6, August, 1950.

Data for six channels are tabulated. The additional recorder was set up on WKBN-FM, 98.9 Mc, due to the interference of this station with WHKC-FM, 98.7 Mc.

158. UBC Report No. 7, September, 1950.

Propagation measurements were made at the Hudson recorder site with the following channels:

a. Columbus-Hudson path:
   (1) WHKC-FM, 98.7 Mc
      (a) Horizontal dipole receiving antenna.
      (b) Vertical dipole receiving antenna.
      (c) Yagi.
   (2) WCOL-FM, 92.3 Mc, horizontal dipole receiving antenna.
b. Detroit-Hudson path:
   (1) WJR-FM, 96.3 Mc, horizontal dipole receiving antenna.
   (2) WXYZ-TV, 179.75 Mc, horizontal dipole receiving antenna.
c. Youngstown-Hudson path: WKBN-FM, 98.9 Mc, horizontal dipole receiving antenna.

A study of noise figures was continued.

159. UBC Report No. 8, October, 1950.

No changes except minor ones.

160. UBC Report No. 9, November, 1950.

One additional receiver was placed in service on the Columbus-Hudson path. Tabulated data is submitted for all paths. Three noise measurement receivers were put in service this month.

161. UBC Report No. 10, December, 1950.

This is a very detailed report on:

a. Performance of REL receivers.
b. Noise figure measurement.
c. Calibration of receiving equipment.
d. Service contour determination for station WHKC-FM.

Data for three paths are tabulated.

162. UBC Report No. 11, January, 1951.

Data for seven recordings is tabulated. (These data are always in the form of hourly median field strengths.) Some modifications were made and a few field calibrations were made of receiving antennas.

163. UBC Report No. 12, February, 1951.

Noise figure measurements and field calibrations are continuing. An eighth recording has been added, using a new high gain plane polarized antenna monitoring WHKC-FM.

164. UBC Report No. 13, March, 1951.

Ten pages of recorded hourly median field data are submitted on WHKC-FM alone, besides data for the other four stations.

165. UBC Report No. 14, April, 1951.

A paper on the project was given at the URSI meeting in Washington, D. C. Data are now reported in decibels above one microvolt per meter for one kilowatt of effective radiated power.

166. UBC Report No. 15, May, 1951.

A major part of the month was spent in preparing for and making field strength measurements on 30 mile radius circles around WHKC-FM, Columbus, Ohio, and WHK-FM, Cleveland, Ohio. In addition, field strength measurements were made on a radial from Youngstown to Hudson. The usual propagation study continues, charts are analyzed, and data are submitted.

167. UBC Report No. 16, June, 1951.

A mobile unit received from CRPL is being fitted out to make field strength measurements on a regular tour of twenty different locations; this is to be operated for one year. The center of the arc along which the twenty sampling sites are located is Columbus, Ohio, about 125 miles away. Otherwise, the regular program is continued.

168. UBC Report No. 17, July, 1951.

The mobile recorder unit is recording two channels, tuned to WHKC-FM, 98.7 Mc and WCOL-FM, 92.3 Mc. The regular recording program continues. Included in this progress report is a graphical analysis of the diurnal variation for a year of recordings of field strength from station WKBN-FM, Youngstown. A detailed description of the mobile recorder unit and its functions is included in this report.

169. UBC Report No. 18, August, 1951.

Recording and noise studies continue. A graphical analysis of the daily variation of data as recorded at Hudson is included in this report.

170. UBC Report No. 19, September, 1951.

Recording and analysis continues. Distribution curves of data are included in this report.

171. UBC Report No. 20, October, 1951.

Propagation measurements were made at the Hudson site on eight receivers and with the mobile unit on two receivers. Diurnal variation curves of data obtained at Hudson are included in this report.

172. UBC Report No. 21, November, 1951.

The regular recording schedule was continued, noise figure measurements were made on all receivers in operation during the month. One antenna change was made at the Hudson recorder site. Analyzed data and graphs are included in this report.

173. UBC Report No. 22, December, 1951.

No changes.

174. UBC Report No. 23, January, 1952.

The program continues as previously set up except for some trouble with antennas due to the weather. Data sheets and graphs are submitted as usual.

175. UBC Report No. 24, February, 1951.

The Hudson recorder site and the mobile unit continue recording. The channel used temporarily to measure the field strength at No. 4 sampling site was changed to KDKA-FM on the 25th of February.

176. UBC Report No. 25, March, 1952.

A resume of the recording project is given in this report. KDKA-FM was recorded on the Pittsburgh-Hudson path using one of the WHKC-FM antennas. Analyzed data and graphs are included in the report.

177. UBC Report No. 26, April, 1952, UBC-T-30.

Propagation measurements of six stations with eight receivers continue at Hudson. The mobile unit records two stations on two receivers. A graphical analysis of the diurnal variation of the hourly median field strength as recorded at Hudson is included in this report. The ratio of simultaneous hourly median values of horizontal field component to vertical field component is presented to determine the condition of operation of the WHKC-FM circularly polarized transmitting antenna.

178 UBC Report No. 27, May, 1952, UBC-T-31.

The regular schedule of field strength recording was continued during May. In April a conference was held in Washington with NBS personnel on the progress of the work.

179. UBC Report No. 28, June, 1952.

The regular schedule continued. Terrain profiles have been prepared for the paths from WHKC-FM to each of the twenty sampling sites used by the mobile unit. The mobile unit concluded the twelve month period of sampling field strength on the 125 mile radius arc. It is scheduled to commence a similar program of sampling measurements on an 85 mile radius arc, starting July 1, 1952.

180. UBC Report No. 29, July, 1952.

Propagation measurements are continued, and a change from station KDKA-FM to WJAS-FM was made on July 3; it became necessary to change back to KDKA-FM on July 22 because of interference on WJAS-FM.

The mobile unit was operated over a regular route sampling twenty sites in North Central Ohio, stations WHKC-FM and WCOL-FM. This is the first month working on a new schedule of sampling at 85 miles from Columbus, Ohio.

A comparison is drawn between the 85 mile and 125 mile arcs. The distance to each site on the two arcs is tabulated and presented in chart form.

181. UBC Report No. 30, August, 1952.

No change.

182. UBC Report No. 31, September, 1952.

No change in schedule. A proposed modification of the chart analysis would effect a simplification in the procedure; it is expected there would be a saving in time of up to 50%, a reduction in errors, and a saving of about 50% in the time spent in checking. (Later experience with these methods modified these conclusions.)

183. UBC Report No. 32, October, 1952.

No change.

184. UBC Report No. 33, November, 1952.

Station WKBN-FM recordings were temporarily discontinued, pending installation of the WKBN-TV antenna. The WKBN-FM recorder channel has been changed to WFMJ-FM, 105.1 Mc, Youngstown, Ohio. Noise figure measurements continue.

185. UBC Report No. 34, December, 1952.

During the last half of December, a time totalizer was used in conjunction with ordinary chart scaling methods.

186. UBC Report No. 35, January, 1953.

Hourly median values of six channels were taken principally from the totalizer record during January. Sampling on the 85 mile arc is now done with one site change each day; interference is experienced at certain sites.

This report includes a tabulation of the final measurements made with the mobile unit on the 85 mile arc. Operation of this phase of the project was concluded on January 31, 1953, after seven months data had been accumulated from twenty sampling sites on the 85 mile arc.

Analysis with the electronic totalizer has not produced the efficiency expected.

187. UBC Report No. 36, February, 1953, UBC-T-40.

A graphical analysis of the diurnal variation of the hourly median field strength as recorded at Hudson is included in this report. Propagation and noise figure measurements were made on all receivers in operation during the month.

Some experimental work has been done in setting up a UHF recorder channel to measure WKBN-TV, Channel 27, and WFMJ-TV.

188. UBC Report No. 37, March, 1953.

No change. Eight receivers are in operation recording four different stations.

189. UBC Report No. 38, April, 1953, UBC-T-42.

No change.

190. UBC Report No. 39, May, 1953, UBC-T-43.

Each month since May, 1952, a statistical distribution has been plotted of the ratio of the simultaneous hourly median values of the horizontal field component to the vertical field component of station WHKC-FM.

191. UBC Report No. 40, June, 1953, UBC-T-44.

This is the 44th and final report on Contract No. CST-10841 with the National Bureau of Standards, which terminated on June 20, 1953, and in which propagation and noise figure measurements were made on eight different channels at the Hudson recorder site and two channels on a mobile unit. Appropriate data and curves on the recorded field strengths are included in the report. A resume of the project is also included.

(d) The Pennsylvania State College. (Author: C. R. Ammerman, Assistant Professor, Electrical Engineering)

192. Penn State Report No. 1, April, 1951.

Preliminary work in instrumentation is described. Exploratory recordings indicate relatively constant signal from nearby stations. Studies of the available signal sources are being conducted, and WHDL-FM, 90 miles, and WRFL-FM, 115 miles, are suggested stations. Receiving equipment is located in the Electrical Engineering Building on the Penn State campus.

193. Penn State Report No. 2, May, 1951.

WHDL-FM, 95.7 Mc, Olean, New York, is being monitored.

194. Penn State Report No. 3, June, 1951.

A statistical study of receiver calibration variations was made and they were found not to be excessive. A second antenna was built and tuned to WJAS-FM, 99.7 Mc, Pittsburgh; recording was started on June 20. WHDL-FM data was studied and compared with published information. On June 28, WTPS, New Orleans, Louisiana, was received for a few seconds over the WHDL-FM receiver.

195. Penn State Report No. 4, July, 1951.

A fourth recording was begun on July 31, monitoring WEST-FM, 107.9 Mc, Easton, Pennsylvania at a distance of 140 miles. Data and diurnal variations for WHDL-FM and

WJAS-FM are given for June and July. WTOP-FM, 96.3 Mc, Washington, D. C., has been chosen as the other eastern station to be recorded. WTOP is about 135 miles away.

196. Penn State Report No. 5, August, 1951.

Four channels are now in operation. Hourly median values of field strength are tabulated, diurnal variations are studied, and terrain profiles of paths are shown for WHDL-FM, and WEST-FM. Tuned doublet type antennas were constructed for each channel, and some improvement was noted in recorder sensitivity due to certain modifications.

197. Penn State Report No. 6, September, 1951.

A terrain profile is shown for WTOP-FM. Tabulations of hourly median field strengths in decibels above one microvolt per meter for one kilowatt of effective radiated power continue, and studies of diurnal variation and rate of fading continue.

198. Penn State Report No. 7, October, 1951.

Exploratory meteorological correlations have not proved significant.

199. Penn State Report No. 8, November, 1951.

The antennas have been checked and some weather protection added. Resistance standards were constructed to aid in measurement of antenna standing wave ratios. Fading studies are progressing. Variations in calibration are being studied. Recording of data and calculations were carried out throughout the month; hourly medians are tabulated.

Discussions were held with W. E. Gordon, L. H. Doherty, J. W. Herbstreit, W. G. Albright, G. V. Waldo, and others regarding the contract and propagation theory.

200. Penn State Report No. 9, December, 1951.

Recording continued throughout December, though difficulty is being experienced with interference of various kinds. An analysis of receiver calibration stability is presented which shows there is a marked improvement over earlier operations; on this basis, the number of calibrations per day has been reduced to approximately three. Values of actual signal levels have been found to greatly exceed those predicted for a smooth spherical earth, but they almost never reach the theoretical values for a plane earth.

201. Penn State Report No. 10, January-February, 1952.

Recording and data analysis continue. Some antennas have been repaired and equipment modified; overall accuracy and stability is under constant study.

A severe external interference was located and eliminated. Included in this report is a preliminary study on fading, a voluntary extra project not required by the contract. Attempted correlation of field strength with certain meteorological factors is continuing.

202. Penn State Report No. 11, March-April, 1952.

Data were recorded and analyzed. Improvements were made in two receivers, and antennas were readjusted. A comparison of fading with wind velocities was completed.

203. Penn State Report No. 12, May-June, 1952.

Recording and analysis continue . Data are being studied for diurnal and seasonal trends.

204. Penn State Report No. 13, July-August, 1952.

All receivers are now crystal-controlled. Recording and analysis of data show high signals now. Included in this report is a copy of a published paper on the low frequency modulator for testing receiver fading, by C. R. Ammerman and R. L. Riddle.

205. Penn State Report No. 14, September-October, 1952.

A search is under way for suitable higher frequency stations to monitor. An experimental receiver for monitoring Channel 10 on TV was assembled. A copy of the paper, "VHF Propagation Beyond the Horizon," published in the November, 1952, issue of the Penn State Engineer is included in this report.

206. Penn State Report No. 15, November-December, 1952.

Two time totalizer recorders were received and put into operation; a receiver for WNBF-TV, Channel 12, Binghampton, New York, is under construction.

Recording proceeds as usual, and data are included in this report. Previously reported studies are continued.

207. Penn State Report No. 16, January-February, 1953.

All four stations are being recorded on Esterline-Angus charts. Two stations, WTOP-FM and WJAS-FM, are also being recorded with the time totalizer and photo-record setup. In analysis of the data, time totalizer records are used whenever possible. Included with this report is a summary description of procedures used in obtaining the hourly median field strength values.

208. Penn State Report No. 17, March-April, 1953.

Recording of VHF field strengths continued throughout April, the contract expiring April 30, 1953. Mr. Riddle and a graduate student hope to continue some experiments.

A paper from this laboratory was presented at the current URSI-IRE meeting in Washington, D. C. on the topic of signal fading. (See Report No. 21 in this list.)

(e) The University of Illinois. (Author: W. G. Albright, EERL UI)

209. Illinois Report No. 1, May, 1950.

Since funds have not yet been established for work to be done on project No. CST 10862, work accomplished by equipment and personnel during this period is limited. No recordings were possible through lack of equipment to be loaned by NBS. Discussions were held as to the possible locations of recording apparatus and the desire to have it on the campus in the Electrical Engineering Building. Some necessary facilities were installed.

210. Illinois Report No. 2, June, 1950.

Recorders and receivers arrived from NBS, and alterations are being made; receivers for TV channel studies will have to be constructed. One receiver designed for aircraft use was converted for use on TV channels.

211. Illinois Report No. 3, July, 1950.

Several NBS receivers are in use, with considerable interference. New stations are being selected to eliminate this problem. Variation of 20% in values obtained by scaling Esterline-Angus charts was experienced by operators. Recordings were made of WXLW, WGNB, and KXCK, with some difficulties.

212. Illinois Report No. 4, August, 1950.

During this period five recording units were installed. Three units are recording FM and two TV signals. Six antenna towers have been designed, five are erected, and work is proceeding on the sixth.

Stations selected for monitoring are:

a. KXOK-FM, St. Louis, Mo., 93.7 Mc, 146 miles.
b. WMBI-FM, Chicago, Ill., 95.5 Mc, 126 miles.
c. WCSI-FM, Columbus, Ind., 93.7 Mc, 139 miles.
d. WNBQ-Ch 5, Chicago, Ill., 81.75 Mc, 126 miles.

213. Illinois Report No. 5, September, 1950.

Three FM stations have been recorded and hourly medians obtained in decibels above one microvolt per meter. Calibrations were made once per week.

214. Illinois Report No. 6, October, 1950.

Monitoring of the three FM stations has continued, and the hourly median values are included in this report. WGN-TV, Channel 9, Chicago, Illinois is being monitored; because of the low signal, a four-element Yagi antenna is being used.

215. Illinois Report No. 7, November, 1950.

Recording of three FM and one TV channel continues, Tower construction is completed.

216. Illinois Report No. 8, December, 1950.

Station WNBQ-TV, 81.75 Mc, Channel 5, Chicago, Illinois has been added to the list of stations being monitored; a seven-element Yagi is used for a receiving antenna.

217. Illinois Report No. 9, January, 1951.

During this period the field strengths of three FM stations and two TV stations were recorded; medians are included in this report for each hour of recording.

Some experimentation with calibration equipment is in progress.

218. Illinois Report No. 10, February, 1951.

Previously listed recordings continue; WGN-TV is being recorded on two antennas now, a folded dipole and a corner reflector.

219. Illinois Report No. 11, March, 1951.

Median FM field strengths are tabulated; TV data will be submitted later. Antenna factors were measured for each of the FM receiving antennas.

220. Illinois Report No. 12, April, 1951.

Effort is being made to correlate variations in atmospheric conditions to changes in received signal strength from the stations located in Chicago, Illinois.

221. Illinois Report No. 13, May, 1951.

Because of interference noted on the WNBQ recording, monitoring of this station will be discontinued, and WBKB will be substituted.

222. Illinois Report No. 14, June, 1951.

Recording and analysis continue . Meteorological data are being collected and analyzed to study correlations with field strength data over the Chicago-Urbana path.

223. Illinois Report No. 15, July, 1951.

Recording of WGN-TV has been discontinued until a REL receiver can be obtained. This station is to be monitored at three different heights above the Electrical Engineering Building, as well as at two different places in the horizontal plane. Several repairs and changes in towers were effected during this period.

224. Illinois Report No. 16, August, 1951.

Monitoring continues on three FM stations and one TV station. Hourly medians are tabulated in the report.

225. Illinois Report No. 1 on Contract No. CST 706, September, 1951.

Recordings of three FM stations and three TV stations are tabulated. One receiver monitors WBKB, 71.75 Mc, Channel 4, Chicago, Illinois, with a standard dipole. Two recording units monitor WGN-TV, 191.75 Mc by a standard dipole with a ground plane, one at 25 feet and the other at 75 feet above the roof of the Electrical Engineering Building. A receiver was installed to monitor WENR-TV, 179.75 Mc, Channel 7, Chicago, Illinois, with a standard dipole thirty feet above the roof.

226. Illinois Report No. 2, CST 706, October, 1951.

Recording and tabulation of hourly medians for three FM stations and three TV stations continue. Also included in the report are some curves obtained from the data.

Meteorological data from radiosonde ascents at Rantoul and Joliet, Illinois, are being collected, as well as data related to ground level atmospheric conditions at several cities within a radius of 200 miles. A correlation of this data with signal strength data is being attempted.

227. Illinois Report No. 3, CST 706, November, 1951.

Recordings of field strengths of WMBI-FM, WCSI-FM, KXOK-FM, WBKB-TV, WENR-TV, and WGN-TV are continued. WGN-TV is recorded with four antennas, three spaced 25 feet apart in the vertical direction and the fourth displaced 40 feet along the horizontal. Data and curves are included in this report.

Fading was prominent during this period, making Esterline-Angus chart scaling difficult. Four amplifiers have been constructed to lessen this difficulty, taking advantage of the totalizer circuits of the REL receivers and fast chart speed EA recording. (Normal speed is three inches per hour with a time delay circuit; fast speed is three inches per minute with no time delay circuit.)

228. Illinois Report No. 4, CST 706, December, 1951.

Each of the four units recording WGN-TV have had a second Esterline-Angus recorder added, operating at three inches per minute. A chart inspector has been designed to allow comparison of five charts simultaneously.

229. Illinois Report No. 5, CST 706, January, 1952.

The WGN-TV data is being studied for height diversity. Otherwise no change in data and curves reported.

230. Illinois Report No. 6, CST 706, February, 1952.

No change.

231. Illinois Report No. 7, CST 706, March, 1952.

In this report the following tables and curves are presented:

a. Hourly median signal strengths: 9 recordings
b. Cumulative distributions: 9 recordings
c. Daily signal strength: 9 recordings

Correlation was attempted between received signal strengths and meteorological data.

232. Illinois Report No. 8, CST 706, May, 1952.

No change.

233. Illinois Report No. 9, CST 706, June, 1952.

No change.

234. Illinois Report No. 10, CST 706, July, 1952.

Hourly median field strengths expressed in decibels above one microvolt per meter for one kilowatt of effective radiated power are tabulated, and curves are also contained in the reports. Some difficulty with local interference from the fire department is experienced on WENR-TV recordings.

235. Illinois Report No. 11, CST 706, August, 1952.

No change.

236. Illinois Report No. 12, CST 706, September, 1952.

Difficulty with the WENR-TV crystal oscillator necessitated deletion of data for the last half of the month for this station.

237. Illinois Report No. 13, October, 1952.

July 1, 1952 WMBI-FM discontinued broadcasting. More than one year's data has been obtained on stations WCSI-FM and KXOK-FM, and it was decided that this was sufficient for these frequencies. New stations are to be chosen for these three recording units. A new crystal was obtained for the recording on TV channel 7, which is now being monitored again.

238. Illinois Report No. 14, CST 706, November, 1952.

Signals from each of the four WGN-TV receiving antennas are being recorded at fast chart speeds for periods of fifteen minutes, in addition to the regular slow speed recordings; these fast speed recordings are made concurrently with measurements of atmospheric conditions by radiosonde.

239. Illinois Report No. 15, CST 706, December, 1952.

During this month it was noted that temperature has a large effect on rectifier components; some modification was made to correct this.

240. Illinois Report No. 16, CST 706, January, 1953.

Preliminary recordings have been made of several Chicago stations in order to find a satisfactory replacement for WMBI-FM.

241. Illinois Report No. 17, CST-706, February, 1953.

Tabulated data and derived curves for six TV recordings are submitted in this report. Station WFMF, 100.3 Mc, has been selected to replace WMBI-FM.

242. Illinois Report No. 18, CST 706, March, 1953.

No change.

243. Illinois Report No. 19, CST 706, April, 1953.

No change except for trouble with the WBKB receiving antenna.

244. Illinois Report No. 20, CST 706, May, 1953.

WBKB and WENR data are omitted because of antenna and equipment trouble.

245. Illinois Report No. 21, CST 706, June, 1953.

Station WFMF has been chosen to be recorded at three different sites along the propagation path; antennas and receiving units have been built for this purpose.

246. Illinois Report No. 22, CST 706, July, 1953.

No change.

247. Illinois Report No. 23, CST 706, August, 1953.

During this period, signal strengths were recorded of station WBKB-TV, as well as those of stations WGN-TV and WENR-TV. Tabulated data and curves are submitted.

248. Illinois Report No. 24, CST 706, September, 1953.

No change except that WBKB-TV changed call letters and frequency and WENR-TV became WKBN. This is the final report on Contract CST 706.

(f) The University of Texas. (Author: DeForrest Metcalf, Electrical Engineering Research Laboratory.)

249. EERL Report No. 1, March 10, 1949.

The scope of the measurement program is outlined, a channel study of FM stations in the State of Texas is presented, equipment for recording VHF field strengths is described, and daily recordings for the month of February, 1949, of KPRC-FM are reported. Some analysis of diurnal variations of these signals is also reported.

250. EERL Report No. 2, April 11, 1949.

Recordings of KPRC-FM for March, 1949, are reported. Development of a totalizer is mentioned. Details of the Houston to Austin path are listed. Receiving and calibrating equipment is described. A bibliography is included.

251. EERL Report No. 3, May 12, 1949.

Hourly median field strengths, scaled manually from Esterline-Angus charts, are tabulated for February, March, and April, 1949. Equipment and methods of measurements and analysis are described in detail. Within-hour Rayleigh distributions for selected hours of recording of KPRC-FM are shown. A bibliography is included.

252. EERL Report No. 4, June, 1949.

Recordings of KPRC-FM for May, 1949, are tabulated.

253. EERL Report No. 5, July 13, 1949.

Recordings of KPRC-FM and KYFM are tabulated. The effect of different time constants of two and five seconds in smoothing the KYFM record is shown, and the KYFM signal is described in some detail. Operation of totalizer equipment is explained. A bibliography is included.

254. EERL Report No. 6, August 12, 1949.

KPRC and KYFM hourly medians are tabulated. Accuracy of measurements is discussed.

255. EERL Report No. 7, September 14, 1949.

KYFM, KPRC-FM and WFAA-FM hourly medians are tabulated. The receiving and recording installation is described in detail.

256. EERL Report No. 8, October 15, 1949.

KYFM, KPRC-FM, and WFAA-FM hourly medians are tabulated. Data were collected to determine the hourly frequency distribution of fading. Equipment changes are discussed.

257. EERL Report No. 9, November 14, 1949.

A summary of absolute accuracy estimates (usually plus or minus one decibel) is given for each set of tables of hourly medians. The beginning of a study of meteorological correlation is indicated.

258. EERL Report No. 10, December 14, 1949.

Data about the propagation paths are tabulated. Some preliminary results of a study of the correlation of meteorological factors with the radio measurements are discussed. Certain matters pertaining to equipment are discussed.

259. EERL Report No. 11, January 11, 1950.

The circuit diagram of the broadcast monitor signal strength analyzer is shown, as well as the diagrams of the VTVM and its power supply. Other groups in EERL are (1) developing instrumentation for computing correlation functions of time series, and (2) studying tropospheric radio scattering.

260. EERL Report No. 12, February 15, 1950.

Field strength measurements made at Austin, Texas, of FM broadcast stations in Dallas, Houston, and San Antonio, Texas, are tabulated. These tabulations cover the months of November, 1949 through January, 1950; in connection with previously reported data, they round out ten months of field strength recording on the Houston signal, eight months on the San Antonio signal, and six months on the Dallas signal. Preliminary estimates of the seasonal variations of tropospheric propagation over the Austin-Houston path are given on the basis of these observations.

261. EERL Report No. 13, March 10, 1950.

This paper describes the results of signal strength measurements of distant FM stations on two receivers using antennas of different directivity. One antenna was a dipole and the other was two horizontally-spaced dipoles separated by one half wave length and fed out of phase. This second antenna had a four decibel gain over the dipole in a horizontal direction and a null in the vertical direction.

The ratio of the signal delivered by the two antennas was found to be a function of the signal strength for stations at 146 and 182 miles. For stronger signals, the directive antenna showed its nominal gain over the dipole antenna. However, for weaker signals the gain of the directive antenna over the dipole was less, and for very weak signals the single dipole indicated a stronger signal.

For an FM station at a distance of 73 miles, the double dipole showed a consistent gain over the single dipole. These data are explained in terms of the theory of scattering recently proposed by Booker and Gordon.

262. EERL Report No. 14, April 14, 1950.

Propagation measurements made over a 146 mile path at a frequency of 102.9 megacycles during the period April 7, 1949 to March 18, 1950 have been analyzed to determine the seasonal effect on the signal as received at various times of the day. The results are given in the form of graphs and statistical tables.

It was found that the average signal strength was lowest in winter and highest in summer, the extent of the difference being around 20 decibels. The overall median signal level was found to be about 9 microvolts per meter, with a standard deviation of the order of 7 decibels, as determined by statistical analysis of 4,670 hourly medians.

263. EERL Report No. 15, May 15, 1950.

Observations of FM field strengths made at the Electrical Engineering Research Laboratory during February, March, and April, 1950 are tabulated in this report for signals arriving over 73,146, and 182 mile paths. These data are presented in hourly median signal strengths. For the 146 mile case, the results together with previously reported data cover 13 months of continuous recording. For the 73-mile and 182-mile cases, the aggregates are 11 months and 8 months, respectively.

The concluding section of the report is a brief discussion of the seasonal cycles as evidenced by the measurements thus far made.

264. EERL Report No. 16, June 6, 1950.

The results of a year's continuous observation of FM field strengths as received at Austin, Texas over 73- and 146-mile paths are summarized in this report. This takes the form of (1) curves showing the smoothed seasonal variations in field strength throughout the year, and (2) statistical tables of percentiles based on hourly median field strengths.

Observations over a 182-mile path have been made for a period of nine months and provide comparison with results obtained over the other paths for all but the early summer months.

Computation of correlation coefficients for the signals received via the two longer paths are described and some of the results given.

265. EERL Report No. 17, July 12, 1950.

Tropospheric radio propagation characteristics observed for the Central Texas area have been examined in conjunction with meteorological measurements. A fair correlation was found between atmospheric humidity at the ground level and radio field strengths observed at Austin, Texas, for a 101.5 megacycle FM station in San Antonio. Somewhat better correlation was had when upper air data in the form of curves of refractive index versus height were utilized.

The influence of atmospheric ducts, substandard lapse rates, etc. appears at least qualitatively to be the same for the area studied as for other areas which have been reported.

266. EERL Report No. 18, August 10, 1950.

Tropospheric radio propagation characteristics at frequencies around 100 megacycles have been measured over several paths in the Central Texas area during the months of May, June, and July, 1950. These measurements, in the form of hourly medians, are tabulated in this report for each day of the three-month period. A brief description is given of certain analyses of these data which are in process.

267. EERL Report No. 19, September 12, 1950.

Field-strength measurements have been made in Austin, Texas, on WFAA-FM in Dallas, Texas, (frequency 97.9 Mc, distance 175 miles) for a period of approximately one year, and a summary of the results is presented. This takes the form of (1) a smoothed curve showing the seasonal variations of field strength from August 1949 through August 1950, and (2) a table of statistical distribution data based on the median levels as determined for each broadcast hour during the year.

A comparative study of tropospheric propagation over the Dallas-Austin path at frequencies of 97.9 Mc and 104.5 Mc is summarized. Fairly good correlation was found for the two frequencies during June, July, and August, 1950, the correlation coefficient of the daily average levels being computed to be 0.64. Field-strength measurements over this path are continuing on 104.5 Mc.

268. EERL Report No. 20, October 11, 1950.

Radio field strengths observed in Austin, Texas, during the month of September, 1950, on FM broadcast stations in Dallas, Houston, and San Antonio, Texas, are reviewed in this report. Various analyses of these measurements are currently in progress and these are briefly described.

269. EERL Report No. 21, November 15, 1950.

Hourly observations of median tropospheric field strength have been made during August, September, and October, 1950 at Austin, Texas, for FM broadcast stations in San Antonio, Houston, and Dallas, Texas. The data are presented in tabular form and in the aggregate amount to approximately 4,150 hourly entries. These complete some 21 months of continuous monitoring of the Houston signal, 17 months for the San Antonio signal, and 15 months over the Dallas-Austin path.

270. EERL Report No. 22, December 12, 1950.

Simultaneous measurements of tropospheric field intensities have been carried out with dipole antennas oriented for the reception of:

(a) Horizontally polarized waves,
(b) Vertically polarized waves propagating horizontally,
(c) Vertically polarized waves arriving from higher elevation angles, up to 90°.

Scatter diagrams showing hourly median signals received on (b) and (c) plotted against (a) are included. These are briefly discussed.

Routine observations of field strength made during November, 1950, are reviewed. Operating experience with the new Type 726 FM Receivers manufactured by Radio Engineering Laboratories, Inc., is described.

271. EERL Report No. 23, January 8, 1951.

Observations of 101.5 Mc tropospheric propagation conditions over the 78-mile San Antonio-Austin path have been made for the 17-month period ending last October, 1950. These data, in the form of hourly median field intensities, have been statistically analyzed in various ways and the results of this are presented in the form of seasonal graphs, statistical frequency tables, and frequency curves. A 6-month cycle seems to be present on the seasonal graph although it is not especially pronounced. The over-all median field strength, as scaled from the appropriate frequency curve, agrees quite well with theoretical computations based on orthodox diffraction in a standard atmosphere. Although rapid short-time fluctuations were quite pronounced, especially during the daylight hours, the dispersion (standard deviation) of the hourly averages was found to be only 5 decibels.

272. EERL Report No. 24, February 14, 1951.

Hourly observations of median field strength have been observed in Austin, Texas for FM broadcast stations in Houston and Dallas, Texas. These data are tabulated for the months November and December, 1950, and January, 1951, and bring the current total up to 24 months of continuous recording over the Houston-Austin path and 18 months over the Dallas-Austin path.

273. EERL Report No. 1-25, March 12, 1951.

During recent months a number of new installations have been made in the equipment being used for measuring, recording, and analyzing VHF field strengths at this Laboratory. Two of the REL Type 726 FM Receivers have been in operation since last December and have resulted in considerable improvement as regards measurement accuracy, calibration stability, resolution of low field strength levels, and continuity of operation. Automatic camera equipment has been in operation since January and provides statistical data on a 24-hour daily basis. This represents a 50% increase over the procedure formerly used.

274. EERL Report No. 1-26, April 11, 1951.

Project activity during March, 1951, under Contract CST-10725 consisted in:

(1) Continuous recording of the signals received at this Laboratory at three VHF frequencies from sources lying at distances up to 175 miles.

(2) Statistical analysis on an hourly basis of the fluctuations of each of these signals.

(3) Computing and plotting graphs showing the secular variations in field strength of each signal.

(4) A survey of concurrent sets of radio propagation data and radiosonde data for several months during 1950, said survey having as its objective the discovery of any significant correlation as may exist between such observations. A summary of these activities is presented in this report.

Also included are six supplemental sheets for attachment to Reports 12, 14, 15, 16, 18, and 21. These provide information as to various corrections to be made on the material as presented in those reports. Although these have been noted briefly in past reports, it has been thought desirable to issue supplemental sheets in which these matters are given special mention. The application of these corrections to our analysis of the 102.9 Mc data in Reports 12 and 15 is discussed and the results are reviewed briefly.

275. EERL Report No. 1-27, May 10, 1951.

Tabulations of hourly median field strength of VHF signals received at this Laboratory over the Houston-Austin and Dallas-Austin paths are presented in this report for the months of February, March, and April, 1951. Information regarding the transmitting and receiving installations is also given and an estimate of accuracy is made. A brief review of operational activities during the subject month is presented and the report is concluded with a brief discussion of current planning.

276. EERL Report No. 1-28, June 8, 1951.

Tropospheric radio propagation measurements made at 102.9 Mc over the 147-mile Houston-Austin path are summarized in this report for the 2-year period ending April 30, 1951. This summary takes the form of:

(1) Smoothed seasonal graphs

(2) Statistical tables showing the frequency distribution of the 9,729 hourly median levels observed during the course of this study.

Current operational activities as of the end of the subject month are also reported along with a brief account of plans for June and July, 1951.

The appendix contains tabulations of some 900 hourly median levels observed at 59.75 Mc/sec for the Houston-Austin path from March 2 through May 31, 1951. Discussion of these is given in the concluding section of the report.

277. EERL Report No. 1-29, July 3, 1951.

Observational, operational, and analytical activities carried on at this Laboratory during June, 1951 under Contract CST-10725 are described. These include routine observations of tropospheric propagation over four paths in the Louisiana-Texas area at seven frequencies in the VHF band. In the section dealing with the operational aspects of the project, a brief account is given of equipment operation and of the status of equipment under construction. Analytical activities for the subject month consisted in routine reduction of the raw data to tables of hourly median field strength levels, and statistical studies based on these hourly medians. Tables of hourly median levels for the period April 25 - May 31, 1951, are included at the end of the report. These data were obtained at a frequency of about 186 Mc for the 176-mile Dallas-Austin path.

278. EERL Report No. 1-30, August 8, 1951.

Observations of 100-megacycle propagation characteristics for two Texas paths, (Houston-Austin and Dallas-Austin) are presented in this report. These take the form of tables of hourly median field strength levels and cover the 3-month period ending July 31, 1951. A brief description of the measuring equipment and procedure is given and the magnitude of experimental errors is estimated.

279. EERL Report No. 1-31, September 28, 1951.

Continuous measurements have been made of the field strength of six VHF broadcast stations as received at the Electrical Engineering Research Laboratory near Austin during the summer of 1951. The results of these are tabulated in the present report and include data on frequencies ranging from 60 to 186 Mc/sec and propagation paths ranging in length from 147 to 275 miles. A brief description of the measuring equipment and its calibration is presented, and an estimate as to the accuracy of the tabulated data is made.

Some recent analytical studies of the influence of atmospheric turbulence on radio propagation through the troposphere are presented in Section IV. The treatment here involves a fresh approach to the subject and some very interesting correlations are brought to light.

280. EERL Report No. 1-32, November 26, 1951.

The results of continuous observation of radio field strength for six VHF broadcast stations in the Louisiana-Texas areas are presented in this report. These observations cover the period September 1 to October 31, 1951 and are reported in terms of hourly median field strength levels for each station. Some 6,000 such median values are tabulated for the subject period.

The reduction process used in deriving these data is described, and an accuracy appraisal of the data is given. Also, a brief description of the receiving and transmitting equipment is included, with specific data on items of particular interest to propagationists. The report is concluded with a brief account of operational and constructional activities connected with the project.

281. EERL Report No. 1-33, January 31, 1952.

Observations of VHF tropospheric propagation conditions in the Texas-Louisiana area during November and December, 1951 are tabulated in this report in terms of normalized hourly median field strength. These cover four propagation paths and include frequencies in the range from 60 to 186 Mc. A brief description of the measuring equipment is given, and an estimate of data accuracy is made. Operational aspects of the program such as equipment maintenance, etc., are discussed in the concluding section of the report.

282. EERL Report No. 1-34, March 28, 1952.

The results of continuous measurement of VHF signal strengths at six frequencies over a variety of propagation paths are presented for the months of January and February, 1952. A brief description of the measuring apparatus and its accuracy limits is given, principally in the form of citations from previous reports. Operational aspects of the program are discussed in the concluding section of the report.

283. EERL Report No. 1-35, May 28, 1952.

The results of continuous observations of radio field strength for six VHF broadcast stations in the Louisiana-Texas area are presented in this report. These observations cover the period March 1 to April 30, 1952 and are reported in terms of hourly median field strength levels for each station. Some 6,000 such median values are tabulated for the subject period.

The reduction process used in deriving these data is described, and an accuracy appraisal of the data is cited. Also, a brief description of the receiving and transmitting equipment is included, with specific data on items of particular interest in propagation studies. An account of non-routine operational activities is given and the report is concluded by a summary of some noise studies carried out in conjunction with the regular field strength recording work.

284. EERL Report No. 1-36, July 31, 1952.

Radio field strength measurements on six VHF broadcast stations in the Texas-Louisiana area are reported for the months of May and June, 1952. A brief account of the measuring equipment used in this survey is given and some comments regarding the reported data are included.

A two-year analysis of the 100 Mc Dallas-Austin propagation data has been completed and the results are presented in the form of seasonal graphs and statistical frequency curves.

285. EERL Report No. 1-38, September 29, 1952.

Tabulated data on hourly median radio field strength observations are submitted with this report for the months of July and August, 1952. These cover six frequencies in the range 60 to 186 Mc/sec and four propagation paths ranging in length from 147 to 275 miles. In the aggregate, the data amount to about 6,500 hourly entries.

Section I, below, is a brief description of the measuring equipment used in this study. Following this in Section II is a condensed discussion of the results concerning such aspects as processing, accuracy, units of measurement, etc. The concluding Section III summarizes our operational experience for the subject period.

286. EERL Report No. 1-39, November 25, 1952.

Observations of VHF radio propagation characteristics are reported herein for the months of September and October, 1952. These cover six frequencies ranging from 60 to 186 Mc and four propagation paths of length varying between 147 and 275 miles. The data are tabulated at the end of this report in the form of median field strengths as determined for each VHF signal for each hour of broadcast.

The textual discussion in the following sections is intended to provide, within a brief scope, the necessary background material required for a proper assessment and utilization of the reported data. More detailed discussions have appeared in earlier reports of this series, giving rather complete descriptions of the measuring equipment, its construction, calibration, and operation. Processing of raw data has likewise been dwelled upon at some length, and these earlier reports should be referred to for amplification of the present treatment.

287. EERL Report No. 1-40, January 29, 1953.

VHF radio propagation measurements made at a site near Austin, Texas are submitted herewith for the months of November and December, 1952. These cover path lengths ranging from 147 to 275 miles and frequencies ranging from 60 to 186 Mc. Supplementing these data is a brief description of the measuring equipment, the accuracies attained, and other factors.

288. EERL Report No. 1-41, March 31, 1953.

Bi-monthly summaries of VHF radio field strength data are tabulated in this report, covering the months of January and February, 1953. Four frequencies in the range of 60 to 186 Mc, as propagated over paths ranging in length from 147 to 275 miles, have been observed.

Beginning January 1 of subject period our recording load was reduced from 6 to 4 channels. The equipment thereby released from service is being reconditioned and will be maintained for standby use.

289. EERL Report No. 1-42, May 29, 1953.

Radio field strength measurements are reported for the period March 1 through April 30, 1953, in the form of monthly tabulations of hourly median levels. Four frequencies have been observed, ranging from 60 to 186 Mc, as propagated over paths varying in length from 147 to 275 miles.

290. EERL Report No. 1-43, June 29, 1953.

VHF radio propagation data for the interval May 1 through June 15, 1953, are presented herewith in the form of tabulations of hourly median field strength levels. These cover four frequencies in the range of 60 to 186 Mc, for paths varying in length from 147 to 275 miles.

After a brief description of the equipment and an account of the data, operational notes covering the subject period are included, along with correction notices for data submitted in our Report No. 1-42. Since the interval covered by this report is the concluding one for the project, a brief historical summary has been presented.

(g) University of Washington, (Author: H. S. Swarm, Instructor, Electrical Engineering Department.)

291. UW Report No. 1, May, 1951.

In this report the preliminary work of Contract No. CST-481, with the NBS, is discussed, in preparation to recording field intensity strengths of FM stations.

Upon consideration of the terrain between the transmitter and the receiver, and because the initial tests show that among six available stations, the least noise interference is on the path of KOIN-FM, 101.1 Mc, Portland, Oregon, 148.5 miles; this station has been selected to be recorded. The receiver will be located in the Electrical Engineering Building on the campus at this time, and a temporary antenna will be used, 94 feet above the ground.

Some equipment has arrived from NBS on loan; other equipment is being built.

292. UW Report No. 2, June, 1951.

Recording of the field strength of KOIN-FM, Portland, for 18 hours per day was started June 22, 1951. The setup of recording equipment was completed early in the month; modifications and repairs were made on the receiver to increase the sensitivity.

Included in this report are the following discussions:

(a) Receiver calibration procedure.
(b) Recording equipment.
(c) Antenna details. (The permanent antenna is completed.)
(d) Procedure of analysis of data.
(e) Noise.
(f) Further work on project.

293. UW Report No. 3, July, 1951.

The permanent dipole antenna was installed early this month, one modification was made in the circuit of the receiver to aid in detecting the noise level.

During the first part of July a local police FM transmitter was found to be causing interference; this was easily adjusted at the receiver.

The hourly median field strength of station KOIN-FM, Portland, Oregon, as received in Seattle, Washington, is presented in tabulated form; a distribution graph is included.

294. UW Report No. 4, August, 1951.

The hourly median field strength as recorded in August of KOIN-FM, was analyzed and put into tabulated data form, as submitted in this report. Some data was lost this month because of noise and interference.

A portable dipole antenna has been completed and will be used in the investigation of variation of field strength with location; possibly this will find a better location for the permanent antenna. Some modifications must be made on the receiver to be used with this portable antenna.

A portable battery-operated field strength meter and a loop antenna have been obtained, and will be used to aid in locating the sources of local interference. This operation should be ready in September, 1951.

295. UW Report No. 5, September, 1951.

The tabulated data of September hourly median field strength, a distribution curve of these values, and a percentage of time curve are all presented in this report.

Since rainy weather has arrived, the average level of the signal seems to be much lower than for previous months. Two high periods occurred at approximately the same time as the passage of a cold front diagonally across the transmission path. A further investigation of this type of phenomenon is planned.

296. UW Report No. 6, October, 1951.

The tabulated data of October hourly median field strength, a distribution curve of these values, and a percentage of time curve are all submitted in this report.

It has been observed that a high in hourly medians occurs between 0700 and 0900 in the morning and again late in the afternoon; this has been correlated with ignition noise from rush hour traffic.

The high signal periods again show correlation with the passage of a high pressure area across the transmission path.

297. UW Report No. 7, November, 1951.

The tabulated data and derived curves as previously reported are submitted for this month.

The same daily peaks have occurred and are correlated with rush hour traffic. The outage from November 18 to 23 was due to a defective receiver part; the receiver was properly retuned on November 23, 1951.

Mr. Robert S. Kirby of NBS, Boulder, Colorado, visited the University of Washington Laboratories concerned with this project on November 28, 1951, bringing a considerable background of information on tropospheric propagation research. Following one of Mr. Kirby's suggestions, KOIN-FM, Portland, now supplies information on any abnormal operation of their transmitting station.

298. UW Report No. 8, December, 1951.

The tabulated data and derived curves as previously reported are submitted in the report for this month.

During almost all of the month the signal was at noise level, rising slightly only on three days: December 10, 11, and 14.

Additional equipment has been received from the NBS, which, with another receiver, will be installed in a University truck to provide a mobile recording unit in the near future.

299. UW Report No. 9, January, 1952.

The hourly median field strength of KOIN-FM, Portland, as recorded during January, 1952, is tabulated and presented in this report; also the derived distribution curve and the percentage of time curve.

On the 14th of January, 1952, the University of Washington education FM broadcast station, KUOW, 90.5 Mc, began regular daily operation; this caused considerable radiation from receivers in the nearby dormitories and interference trouble on the KOIN-FM recording project.

Modifications are being made on Cooke receiver which arrived early this month.

The meteorology department is assisting in determining the necessary meteorological conditions for favorable propagation. Very good correlation of medium and high signal strengths has been achieved with anticyclonic winds due to a high pressure area west of the Pacific Coast. This weather condition gives a positive temperature gradient and a negative moisture gradient with increasing height and is favorable to a large change in the index of refraction, the necessary conditions for reception of KOIN-FM in the Seattle area.

300. UW Report No. 10, February, 1952.

The usual schedule of analyzing data and obtaining the distribution curve and the percentage of time curve has been carried out. The interference troubles due to broadcasting by the University of Washington educational FM station, KUOW, have been negligible.

Work is progressing on the modification of the Cooke receiver. A correlation study is in progress concerning field strength and meteorological conditions.

301. UW Report No. 11, March, 1952.

No change.

302. UW Report No. 12, April, May, June, 1952.

Tabulated data of analyzed hourly median field strengths and the curves derived from the data are presented for the months of April, May, and June, 1952. It is planned to issue quarterly reports in the future.

Much time was spent on the modifications of the Cooke receiver which is still not in satisfactory condition for continuous recording. Erratic operation of the recorder has caused a large portion of the data for May and early June to be deleted. Normal operation was resumed in mid-June.

303. UW Report No. 13, July, August, September, 1952.

The hourly median field strengths as recorded of KOIN-FM during the third quarter of 1952, and presented in tabulated data form are included in this report, also the derived distribution curves of the data and the plotted graphs of percentage of time for which the hourly median exceeds a given value.

During July and August, 1952, the equipment was maintained in operation but no analysis was attempted, due to most of the personnel being absent from the University of Washington.

In September the installation of some equipment in the Mobile Laboratory was started.

304. UW Report No. 14, October, November, December, 1952.

The hourly median field strengths in decibels above one microvolt per meter for one kilowatt of effective radiated power for the three months of the last quarter are presented. Three graphs are presented showing the diurnal distribution of the hourly medians, and three other graphs show the percentage of time the hourly median exceeded a given field strength.

The preparation of the Mobile Electronics Laboratory was completed with a few adjustments in the equipment. A field trip was made and provisional points have been selected; preliminary tests suggest that better signals can be expected away from the campus.

305. UW Report No. 15, January, February, March, 1953.

The hourly median field strength of KOIN-FM, Portland, during the first quarter of 1953 is shown in tabulated form. The distribution curves of hourly median values and of percentage of time for which the hourly median exceeded a given value are presented in six graphs.

This contract ended in January, 1953.

The Mobile Laboratory was used to secure data at two additional sites away from the main recording site at the Electrical Engineering Building. Two weeks of recording were made at the top of Squak Mountain, and two weeks of recordings were made on the roof of the Telephone Exchange Building in downtown Seattle.

306. The Squak Mountain Report, November, 1951.

Four stations, KIRO, KOMO, KING-TV, and KRJ sponsored a field survey of transmissions from the top of Squak Mountain, in order to determine the best selection of VHF and UHF transmitter sites in the Seattle area. Actual field work was performed on November 8 and 9, 1951 at recording sites along radials from Squak Mountain through downtown Seattle. Recordings were obtained on 49.5 Mc and 154.57 Mc with omnidirectional antennas and 35 watts of effective radiated power. A log was kept of recording locations versus chart time.

This report goes into detail on the following:

(a) Description of survey.
(b) Transmitting equipment used.
(c) Receiving and recording equipment used.
(d) Calibration of recording equipment.
(e) Data Analysis.
(f) Interpretation of data.
(g) Conclusions drawn.
(h) Tables of radials used.

Included in the report are terrain profiles and photographs of Seattle and of the recorder charts.

A supplementary list of technical reports will be found on pages numbered 112 through 112q.

307. Kenneth A. Norton, "The Effect of Fading on the Desired-to-Undesired Signal Ratio Required to Provide a Specified Grade of Service for a Given Percentage of a Specified Period of Time," CRPL Report 4-M-5, February 3, 1948.

ABSTRACT

It is the purpose of this memorandum to outline the factors involved in determining the allowance for fading which must be made in the allocation of two stations operating on the same or adjacent radio frequencies in order to provide a specified grade of service for a given percentage of a specified period of time. Factors accounted for include transmitter powers, antenna directivities, propagation path lengths, long-term and short-term fading, expected median field strengths, and various possible definitions of grade of service.

308. Kenneth A. Norton, "Sunspots and Very High Frequency Radio Transmission," CRPL Report 4-3, October 29, 1947; see also QST, Vol. 31, No. 12, p. 13, December, 1947.

ABSTRACT

At the present time, 1947, the activity of sunspots as measured by Zurich sunspot numbers is at a higher level than it has ever reached since the discovery of radio during the latter part of the 19th century. A detailed discussion of the expected increase in maximum usable frequencies leads to the conclusion that the coming winter will afford many opportunities for the amateurs to make new and interesting long-range contacts using very low-powered transmitters on the 50-megacycle band.

309. "Extension of FM Broadcast Range," NBS Tech. News Bulletin, Vol. 32, No. 4, April, 1948.

ABSTRACT

Experimental research conducted by the National Bureau of Standards indicates that the reliable service areas of frequency modulation broadcasting stations using transmitters now available may be extended far beyond the horizon. The most effective way to increase the service range of an FM broadcasting station is to increase the transmitting antenna height rather than the power, since such a change increases the service range more rapidly than the interference range, resulting in a more efficient utilization of the channel. It seems, also, that there may exist an optimum frequency for propagation to large distances beyond the horizon.

310. "VHF-UHF Range Tests," letters to Wright Field, November 6, 1947, January 29, 1948, and April 22, 1948.

ABSTRACT

These letters are technical memoranda with the object of informing the Air Material Command of the progress of CRPL on the problem of analyzing the propagation characteristics of VHF and UHF for use in air-to-air and air-to-ground communication

Comment

The three letters, with associate figures, are reproduced here as Supplement XIX.

311. R. S. Kirby, "Analysis of the Ground Wave and Tropospheric Wave Field Intensity Variations at a Distance Far Beyond the Line-of-Sight for an FM Broadcasting Station Operating on 99.7 Mc," CRPL working document for the FCC Ad Hoc Committee, March 18, 1949.

ABSTRACT

For the purpose of obtaining a better understanding of the nature of the variation in field intensities at large distances

far beyond the line-of-sight in the frequency modulation broadcast band, field intensity recorders were installed at the National Bureau of Standards in Washington, D. C., late in 1947, and continuous recordings were made of the field strengths of several FM broadcast stations. This report analyzes one of the most complete sets of recordings, that of WSAP-FM in Portsmouth, Virginia.

Comment

This report is reproduced here as Supplement XX.

312. K. A. Norton, "Propagation Over Rough Terrain," US NEL Symposium, July 25, 1949, NE 120301 Report 173 Problem NEL 1A1, p. 101, U. S. Navy Electronics Laboratory, San Diego, California.

ABSTRACT

It is intended here to describe some of the characteristics of two important mathematical tools useful in statistical predictions of ground-wave propagation, and to demonstrate, by an example, their applicability to the description of radio propagation over rough terrain.

Comment

This report is reproduced here as Supplement XXI.

313. J. H. Chisholm, "Measurements of Microwave Diffraction Over Trees," US NEL Symposium, July 25, 1949, NE 120301, Report 173, Problem NEL 1A1, p. 114, U. S. Navy Electronics Laboratory, San Diego, California.

ABSTRACT

Because many propagation paths, especially in the eastern United States, contain tree foliage to heights of 70 and 100 feet, an investigation to determine quantitatively the effect

of such foliage upon microwave propagation was undertaken by the Central Radio Propagation Laboratory. Controlled experiments were conducted over a 4000-foot path at a wavelength of six centimeters; metal screens and actual tree foliage were used as diffracting obstacles.

Comment

This report is reproduced here as Supplement XIV.

314. A. W. Straiton, D. F. Metcalf, C. W. Tolbert, "A Study of Tropospheric Scattering of Radio Waves," Proc. IRE, Vol. 39, No. 6, p. 643, June, 1951.

ABSTRACT

The theory of tropospheric scattering of radio waves recently advanced by Booker and Gordon makes the prediction that radio-frequency energy may arrive from a ground-based VHF transmitter at angles well above the horizon, and also that signals received as a result of the scattering process will attenuate less rapidly with distance if the polarization of the source is horizontal than if it is vertical. Experimental observations made at wavelengths of 3 meters and 3 centimeters have verified these deductions.

315. "Study of Tropospheric Propagation of Radio Waves," Quarterly Progress Report No. 4, January 1, 1955 to March 30, 1955. NBS Report No. 3530.

316. A. F. Barghausen, M. T. Decker and L. J. Maloney, "Measurements of Correlation, Height Gain, and Path Antenna Gain at 1046 Megacycles on Spaced Antennas Far Beyond the Radio Horizon," IRE Convention Record, 1955, Vol. 3, Part 1, Antennas and Propagation.

ABSTRACT

Studies made and reported by the National Bureau of Standards in 1953 on the correlation of 1046 Mc radio fields on spaced antennas at distances far beyond the radio horizon are supplemented by more recent measurements. In addition

to the correlation of instantaneous fields, the correlation of hourly median fields and the diurnal variation of the received signal are shown. Simultaneous measurements from a parabolic reflector antenna are used to indicate the loss in gain relative to the expected free space gain of a large aperture array.

317. "Survey of Propagation Characteristics of Sea Test Range in Vicinity of the Naval Air Missile Test Center, Point Mugu," Progress Report No. 1, April 1, 1955, USNAMTC Project TED EL-42036. NBS Report No. 3531.

318. "Large Reduction of VHF Transmission Loss and Fading by the Presence of a Mountain Obstacle in Beyond-Line-of-Sight Paths," letter to the editor, Rebuttal by J. W. Herbstreit. Proc. IRE, Vol. 43, No. 5, pp. 627-628, May 1955.

319. A. P. Barsis, B. R. Bean and K. O. Hornberg, "Cheyenne Mountain Tropospheric Propagation Data February-March 1954," NBS Report No. 3536, May 1, 1955

ABSTRACT

This report describes tropospheric propagation measurements taken over the Cheyenne Mountain paths on frequencies between 92 and 1046 Mc during February, 1954. The results of the measurements are given in terms of cumulative distribution of hourly medians (in units of basic transmission loss), diurnal variations and interdecile range of hourly medians of transmission loss, and dependence of the above quantities on the angular distance Θ. Results of meteorological measurements on the 500-foot tower at Haswell, Colorado, are also shown together with radiosonde data obtained at Denver, Colorado, and Dodge City, Kansas, during the recording period. A general description of the weather during the measurement period is also given.

320. E. F. Florman, "A Measurement of the Velocity of Propagation of Very-High-Frequency Radio Waves at the Surface of the Earth," Journal of Research, Vol. 54, No. 6, June 1955, Research Paper 2596.

ABSTRACT

The velocity of propagation of electromagnetic waves was measured at the surface of the earth, using a radio-wave interferometer operating at a frequency of 172.8 Mc. The measured phase velocity, converted to velocity in vaccum, or the "free-space" value, was found to be 299795.1 ±3.1 km/sec.

The accuracy with which the free-space phase velocity of radio waves could be measured was limited primarily by the accuracy to which the refractive index of air could be obtained from measured values of pressure, temperature, and relative humidity.

321. J. W. Herbstreit and M. C. Thompson, "Measurements of the Phase of Radio Waves Received over Transmission Paths with Electrical Lengths Varying as a Result of Atmospheric Turbulence," Proc. IRE, Vol. 43, No. 10, pp. 1391-1401, October, 1955.

ABSTRACT

A system for the measurement of the variations in electrical lengths of radio propagation paths is described. The observed path-length instabilities are considered to be caused by the same atmospheric turbulence responsible for the existence of very high frequency and ultra high frequency fields far beyond the radio horizon. Results obtained on 172.8 Mc and 1,046 Mc along 3½-, 10-, and 60-mile paths are reported.

322. K. A. Norton, L. E. Vogler, W. V. Mansfield and P. J. Short, "The Probability Distribution of the Amplitude of a Constant Vector Plus a Rayleigh-Distributed Vector," Proc. IRE, Vol. 43, No. 10, October, 1955.

ABSTRACT

Formulas, tables, and graphs are given for the probability distribution of the instantaneous resultant amplitude of the sum of a constant vector and a Rayleigh-distributed vector. It is emphasized that two distributions are required to describe a Rayleigh-distributed vector: the distribution of its amplitude and the distribution of its phase. References are made to ways in which these distributions may be used to describe random variables occurring in ionospheric, tropospheric, and irregular terrain propagation problems. Finally, a discussion is given of amplitude and phase distributions of two other random vectors encountered in tropospheric propagation studies.

323. K. A. Norton, P. L. Rice and L. E. Vogler, "The Use of Angular Distance in Estimating Transmission Loss and Fading Range for Propagation Through a Turbulent Atmosphere over Irregular Terrain," Proc. IRE, Vol. 43, No. 10, pp. 1488-1526, October, 1955.

ABSTRACT

A discussion is given of the transmission loss expected in free space with various types of antennas, followed by a description of theoretical prediction curves for the transmission loss expected in tropospheric propagation on over-land paths. Angular distance is shown to be useful for predicting the short term within-the-hour fading range as well as the median transmission loss. Illustrations are presented of the theoretical dependence of transmission loss on the angular distance, transmission path length, antenna height, radio frequency, and a parameter ΔN which is a measure of the vertical gradient of atmospheric refractive index. The radio data indicate that the magnitude of the scattering cross section decreases in inverse proportion to the radio frequency in the range we have studied.

A new theory of obstacle gain is developed, and it is shown that this is particularly useful for explaining some of the unusually strong fields which have been observed just beyond the horizon in over-land propagation.

Theoretical curves of the average value of the path antenna gain to be expected in tropospheric forward scatter propagation are presented as a function of the angular distance, the asymmetry factor, and the free space gains of the transmitting and receiving antennas.

324. K. A. Norton, P. L. Rice, H. B. Janes, and A. P. Barsis, "The Rate of Fading in Propagation through a Turbulent Atmosphere," Proc. IRE, Vol. 43, No. 10, pp. 1341-1353, October, 1955.

ABSTRACT

Fading rate is defined to be the number of times per minute that the envelope of the received field crosses its median level with a positive slope. It is shown that this definition of fading rate provides a quantity which is numerically related to the parameters of the propagation medium under certain conditions which are normally satisfied in either ionospheric or tropospheric propagation studies. The pertinent parameters of the propagation medium in beyond-the-horizon transmission are the location and shape of the scattering volume and the turbulent and drift velocities of the scatterers. An extensive discussion is given of the shape of the tropospheric scattering volume for beyond-the-horizon transmission. An analysis is then given of some fading rate data obtained in the National Bureau of Standards tropospheric propagation program in the 92 to 1046 Mc range of frequencies on transmission paths 70, 97, 226, and 394 miles in length. Finally an analysis is given for within-the-horizon propagation. In this case it is advantageous to define fading rate as the number of times per minute that the phase of the received field crosses its median level with a positive slope.

325. M. T. Decker, "Propagation Aspects of TACAN System Coverage," For ANDB Symposium on TACAN at Washington, D. C., November 3 - 4, 1955, NBS Report No. 3556, October 27, 1955.

ABSTRACT

The propagation factors which affect the coverage volume of a TACAN type facility operating in the 1000 Mc region are discussed in this paper. Using theoretical and empirical methods, prediction curves are derived which indicate the probability of receiving satisfactory service in a given volume of air space.

326. Bradford R. Bean, "Some Meteorological Effects on Scattered Radio Waves," NBS Report No. 3561, December 15, 1955.

ABSTRACT

The long term variations of received scattered fields due to atmospheric effects are estimated for frequencies of 100 to 50,000 Mc and over propagation paths of 100 to 1000 miles. The

long term variations are presented in two parts: (1) empirically derived variations excluding absorption and (2) theoretically derived variations due to gaseous atmospheric absorption. The absorption effects are obtained by following a scattered radio wave through an actual atmosphere.

327. K. A. Norton, "Point-to-Point Radio Relaying Via the Scatter Mode of Tropospheric Propagation," NBS Report No. 3562, December 21, 1955.

ABSTRACT

Formulas are given for determining the transmitter power required to provide a specified grade of service in point-to-point radio relaying of the following types of signals; television, frequency modulation high fidelity music, frequency modulation voice, frequency shift telegraph, and a just measurable signal. Allowance is made for the antenna gains, the carrier frequency, the systems bandwidth, distance, the antenna heights above the ground and the effects of the terrain and the atmosphere along the transmission path.

328. R. S. Kirby and F. M. Capps, "Correlation in VHF Propagation over Irregular Terrain," Trans. IRE, AP-4, pp. 77-85, January 1956.

ABSTRACT

A study has been made of the correlation in transmission loss observed over irregular-terrain paths. Simultaneous mobile measurements were made of two pairs of VHF broadcasting stations in Washington, D. C.-Baltimore, Maryland area. The correlation coefficients derived from sample sets of transmission loss data indicate that when reception is from opposite directions, no significant correlation is evident, and when the paths of propagation are the same even though the frequencies are separated considerably, the correlation appears to be significantly high.

329. R. S. Kirby, H. T. Dougherty, and P. L. McQuate, "VHF Propagation Measurements in the Rocky Mountain Region," NBS Report No. 3564, January 2, 1956.

ABSTRACT

Mobile measurements of VHF propagation over various irregular terrain paths have been made by the National Bureau of Standards in the Colorado Rocky Mountain region in an effort to evaluate terrain effects upon broadcast and point-to-point communications at very high frequencies. Mobile measurements of the varying path transmission loss were obtained in a continuous manner while driving along selected routes with a mobile field strength recording unit, which consists of a modified house trailer equipped with a telescoping mast and pulled by a pick-up truck. The paths used ranged from relatively smooth to very rough.

The results of the measurements are considered in the light of current irregular terrain theory. The correlation of sector median transmission loss for different frequencies over irregular terrain tends to be high when the paths are nearly the same, becoming significantly less when the paths diverge. This would indicate that the frequency selectivity of an irregular terrain path is small.

330. First Annual Report of the Boulder Laboratories, July 1, 1954 to June 30, 1955, NBS Report No. 3566.

331. H. T. Dougherty, Appendix E to "The Propagation Characteristics of the Frequency Band 152-162 Mc Which is Available for Marine Radio Communications."

ABSTRACT

To permit an estimate of the expected service range for propagation paths over sea or fresh water in the frequency band 152-162 Mc, a nomograph is presented for a range of values of height and separation of a transmitting and a receiving antenna. This nomograph will permit an estimate of the expected service range for propagation over a smooth spherical earth, through a standard atmosphere.

332. "Cheyenne Mountain Tropospheric Propagation Measurements August 1954," Final Report, NBS Report No. 3568, February 6, 1956.

333. R. S. Kirby and A. P. Barsis, "Survey of Propagation Characteristics of Sea Test Range in Vicinity of the Naval Air Missile Test Center, Point Mugu," Progress Report No. 2, NBS Report No. 3572, March 9, 1956.

334. A. P. Barsis and R. E. McGavin, "Report on Comparative 100 Mc Measurements for the Transmitting Antenna Heights," Trans. IRE, Vol. AP-4, No. 2, April, 1956.

ABSTRACT

This report evaluates measurements taken during August, 1952, at a frequency of 100 Mc as transmitted from three transmitting sites at elevations ranging from 6,220 feet to 14,110 feet above mean sea level. Six receiving sites were used ranging in distance from approximately 50 miles to 620 miles from the transmitter sites. Results are presented in terms of hourly medians of recorded field intensity and their distributions, as well as the over-all median values and deviations derived from these distributions.

335. "Radio Studies of Atmospheric Turbulence," by Section 83.60. NBS Report 3579, dated April 2, 1956.

ABSTRACT

Variations in the density and composition of the air in the earth's atmosphere cause the phase velocity of propagation of a radio wave to vary, in general, from point-to-point in the atmosphere and at any given point, to vary with time. These changes in velocity (or refractive index) act to produce two effects which may be studied experimentally. The first of these effects will be termed "scattering" and the second, "phase surface distortion" or more simply, "phase distortion."

The value of scattering for long distance communication systems has been clearly established and considerable experimental and theoretical work has been done to facilitate the engineering design of practical systems. The phase distortion effect of the atmosphere may be observed on relatively short, within-line-of-sight paths.

This report has been divided into 11 sections which include descriptions of the physical techniques, the instrumentation and the treatment of data, and a final section in which the results are summarized and interpreted. Eleven appendices containing supplementary discussions are included.

336. James R. Wait, "On the Theory of Propagation Along a Curved Surface," NBS Report No. 3583, dated May 5, 1956.

ABSTRACT

The method of solution is outlined for the problem of propagation of vertically polarized waves along a surface whose curvature and electrical properties have a discontinuity. The mutual impedance between two short vertical antennas on either side of the boundary of separation is considered to be the fundamental quantity which is sought. It is shown that to a first order of magnitude, the effect of the conductivity contrast and curvature change are additive corrections to the mutual impedance between dipoles over a single homogeneous spherical surface.

337. James R. Wait, "A Basis of a Proposed Method to Measure the Characteristics of an Arbitrary Downcoming Radio Wave," NBS Report No. 3587, dated May 9, 1956.

ABSTRACT

It is the purpose of this note to outline a scheme for measuring the angle of arrival, azimuth, and polarization of a downcoming radio wave from measurements made on the ground.

338. NBS Boulder Laboratories Annual Report, NBS Report No. 3592, dated June 19, 1956.

339. James R. Wait, "Transient Behavior of the Electromagnetic Ground Wave on a Spherical Earth," NBS Report No. 3595, dated July 17, 1956, Presented at URSI meeting, University of Florida, Gainesville, Florida, December 1955.

ABSTRACT

Some calculations are presented to show the nature of the transient ground wave radiated from an electric dipole which is

situated over a spherical earth. The moment of the dipole is considered to vary with time in a linear manner. It is shown that the departure of the leading edge of the radiation field from a step function form is a consequence of diffraction and loss in the finitely conducting ground.

340. M. C. Thompson, Jr., and M. J. Vetter, "A Microwave Refractometer for Use in Small Aircraft," NBS Report No. 3597, dated July 24, 1956.

ABSTRACT

The importance of an airborne microwave refractometer as a tool in the study of tropospheric radio scattering has been recognized for some years. A considerable amount of work has been done using both of the two types of instruments thus far developed and some valuable knowledge has been gained concerning the nature of atmospheric turbulence. The purpose of this work has been to bring some of the development up to date with respect to circuit techniques and components and to improve the design wherever possible to increase useful sensitivity and reliability and at the same time provide an instrument requiring less operator attention. Experience gained from the use of previous models suggested, for example, that there might be some significant advantages to the use of smaller aircraft for this work, consequently one of the objectives of this design was to reduce weight, size, and power requirements.

341. V. H. Goerke and R. S. Lawrence, "Galactic and Solar Radio Emission as the Limiting Background Noise in Systems Using Ionospheric and Tropospheric Scattering," NBS Report No. 3598, August 3, 1956.

ABSTRACT

The background radio noise intensity produced by emission from galactic and solar sources is evaluated as the limiting noise for communication systems employing large-aperture antennas. A procedure is given for estimating background intensities from a sky map of galactic temperature contours. The maximum and minimum expected radio noise levels are evaluated over a frequency range from 25 to 10,000 Mc/s for various antenna apertures, and are reported in graphs as noise intensity in decibels above kT_0B (T_0 = 300° K).

Basic data have been obtained from published radio-astronomy surveys, from solar measurements at the National Bureau of Standards, and from measurements made with various antennas used in the investigation of scatter propagation at VHF.

The expected variations and fluctuations in solar radio noise emission are discussed.

Charts and tables enable the reader to estimate the background noise in any given antenna system.

342. A. P. Barsis and F. M. Capps, "Survey of Propagation Characteristics of Sea Test Range in Vicinity of the Naval Air Missile Test Center, Point Mugu," Progress Report No. 3, NBS Report No. 5003, dated August 10, 1956.

343. R. W. Hubbard, "Study of Tropospheric Propagation X-Band Propagation System Development," First Quarterly Progress Report March 1, 1956 - May 31, 1956, NBS Report No. 5005, dated May 31, 1956.

344. B. R. Bean, "Survey of the National Bureau of Standards' Application of Atmospheric Refractivity Measurements to Radio Propagation Studies," NBS Report No. 5007 dated August 20, 1956.

ABSTRACT

A brief general review is made of the National Bureau of Standards' application of radio refractivity data to tropospheric radio propagation problems. An appendix lists various groups of radio meteorological data available at the National Bureau of Standards.

345. R. W. Hubbard, "Study of Tropospheric Propagation X-Band Propagation System Development," Second Quarterly Progress Report June 1, 1956 - August 31, 1956, NBS Report No. 5015, dated August 31, 1956.

346. R. S. Kirby, "Measurement of Service Area for Television Broadcasting," NBS Report No. 5020, dated October 19, 1956.

ABSTRACT

It is proposed that the present definition of television service in terms of iso-probability contours be abandoned. A new definition of service area, first proposed by Norton and Gainen in 1950, is recommended in its place. This provides a much more useful measure of service and makes the estimating techniques more tractable.

347. M. T. Decker, "Tacan Coverage and Channel Requirements," NBS Report No. 5025, dated October 29, 1956.

ABSTRACT

Tacan is a radio air navigation system of the polar coordinate, or rho-theta, type. The National Bureau of Standards has been asked to estimate the number of channels which would be required to implement the Tacan system in the continental United States under certain assumptions. This report presents the essential results of this study.

348. James R. Wait, "The Pattern of a Flush Mounted Microwave Antenna," NBS Report No. 5028, dated October 25, 1956.

ABSTRACT

The numerical results for the far zone radiation from an axial slot on a circular cylinder of perfect conductivity and infinite length are discussed. It is shown that the results for large diameter cylinders can be expressed in a universal form which is suitable for pattern calculations for arrays of slots on a gently curved surface. The work is compared with a related diffraction problem considered by Fock.

349. M. C. Thompson, Jr., and M. J. Vetter, "Single Path Phase Measuring System for Three-Centimeter Radio Waves," NBS Report No. 5035, dated December 19, 1956.

ABSTRACT

A system has been developed using the same general approach previously employed at 1046 Mc, for measuring variations in phase-of-arrival of 3 cm radio waves propagated along a line-of-

sight path. The techniques for obtaining the necessary frequency stabilization are discussed in detail together with some estimates of the system performance.

350. R. W. Hubbard, "Development of an X-Band Field Intensity Recording System for Tropospheric Propagation Studies," Third Quarterly Progress Report September 1, 1956 - November 30, 1956, NBS Report No. 5036, dated November 30, 1956.

351. H. B. Janes and P. I. Wells, "Some Tropospheric Scatter Propagation Measurements Near the Radio Horizon," Proc. IRE, Vol. 43, No. 10, pp. 1336-1340, October, 1955.

ABSTRACT

Measurements of small variations in 100 Mc field intensity within and just beyond the radio horizon are reported. The measured fields are assumed to be the resultant of two field components, one having a constant amplitude and the other being a rapidly-fading scattered component. Median values of transmission loss for the scattered component and for the measured signal are plotted versus the angular path distance, Θ. Measurement of the correlation of field strengths received on two horizontally - spaced antennas within the radio horizon is reported. When the spacing was varied from $\frac{1}{2}$ to 20 wavelengths and the correlation compared to other characteristics of the field, the correlation was found to be as much a function of transmission loss and fading rate as it was of antenna spacing.

352. Harold Staras, "Forward Scattering of Radio Waves by Anisotropic Turbulence," Proc. IRE, Vol. 43, No. 10, pp. 1374-1380, October, 1955.

ABSTRACT

This paper extends the theory of tropospheric scatter by deriving the appropriate formulas for the important radio system parameters under the assumption that the turbulence is anisotropic; i. e., that the scale of turbulence in the horizontal dimension is different from the scale of turbulence in the vertical dimension. The frequency dependence of the scattered radiation is the same for anisotropic large-scale turbulence as for isotropic. Furthermore, those radio systems parameters which depend only on the rate of decrease of scattered energy with elevation angle (such as the vertical correlation function and height gain) remain unchanged

under the assumption of anisotropy while those parameters which depend on the energy coming out of the great circle plane (such as the horizontal correlation function) can be influenced quite substantially by anisotropy. Several other parameters such as the longitudinal correlation function, bandwidth of the medium and effective antenna gain may also be influenced by anisotropy but generally to a lesser extent. A comparison is made between our theory and some recent NBS data indicating that anisotropy does exist.

353. G. Birnbaum and H. E. Bussey, "Amplitude, Scale, and Spectrum of Refractive Index Inhomogeneities in the First 125 Meters of the Atmosphere," Proc. IRE, Vol. 43, No. 10, pp. 1412 - 1418, October, 1955.

ABSTRACT

An extensive series of observations was obtained with two refractometers and meteorological equipment installed on various levels of a 128-meter tower at the Brookhaven National Laboratory, Long Island, New York. One of the refractometers was equipped with a multiple cavity unit for the study of correlation between two positions in the horizontal direction. The errors arising from the exposure of the cavity to the atmosphere and its ventilation were investigated.

The amplitude of the refractive index variations could be correlated with various meteorological conditions. From the experimentally determined cross-correlation coefficient, and assuming that its variation with distance is given by the exponential (Taylor) form, scales in the neighborhood of 60 meters were obtained. A crude analysis of the data indicated that the intensity of the refractive index inhomogeneities varied, on the average, as the 1.6 power of their size.

354. B. R. Bean and F. M. Meaney, "Some Applications of the Monthly Median Refractivity Gradient in Tropospheric Propagation," Proc. IRE, Vol. 43, No. 10, pp. 1419-1431, October, 1955.

ABSTRACT

A consistent correlation has been found between the monthly median values of 100 Mc transmission loss and an atmospheric

parameter ΔN which is determined from standard radiosonde observations. ΔN is defined as the difference between the refractivity at the earth's surface and at one kilometer above the earth's surface. ΔN is determined from the midpoint of the propagation path and is taken to represent an effective gradient of the refractive index. It is found to yield correlation coefficients with transmission loss of about 0.7 even in the far scattering region. This correlation is also used to derive estimates of the annual, geographic, and terrain variances of the transmission loss. Six-year average values of ΔN are presented for the United States and can be used as an aid in the prediction of the annual cycle of 100 Mc transmission loss. The possibility of using surface observations of N for times of day other than the radiosonde observation hours is examined and found to be encouraging.

355. R. S. Kirby, H. T. Dougherty and P. L. McQuate, "Obstacle Gain Measurements Over Pikes Peak at 60 to 1,046 Mc," Proc. IRE, Vol. 43, No. 10, pp. 1467 - 1472, October, 1955.

ABSTRACT

Radio transmission loss measurements made over four propagation paths approximately 100 miles in length show the effect of a large mountain obstacle on VHF and UHF ground-to-ground propagation. Recordings of transmission loss were obtained at four sites as a function of receiving antenna height and by mobile measurements along a route normal to the propagation path.

Measurements for propagation directly over Pikes Peak exhibit the well defined lobing associated with four ray-path diffraction theory. Theoretical approximations based on the Fresnel-Kirchhoff scalar knife-edge diffraction theory predict values of transmission loss and lobe structures which are in good agreement with those observed.

Measurements for propagation to the east and west of Pikes Peak are characterized by lower fields at all frequencies and large fading ranges.

COMMENT

Additional publications in the Proc. IRE, Vol. 43, No. 10, October, 1955, are numbered 321-324 in this supplementary list of technical reports.

356. B. R. Bean and R. L. Abbott, "Oxygen and Water Vapor Absorption of Radio Waves in the Atmosphere," to be published in the July, 1957 issue of Geophysica Pura E Applicata.

ABSTRACT

Calculated values of the gaseous atmospheric absorption are presented for the frequency range 100 to 50,000 Mc at elevations above ground up to at least 130,000 feet, for average conditions during February and August at Bismarck, N. D., and Washington, D. C. Total radio path absorptions are presented for tropospheric forward scatter communication links for distances of 100, 300 and 1000 miles. The total path absorptions were calculated by summing the absorption contributed by each portion of the atmosphere traversed by a radio ray passing from a 60 foot parabolic antenna resting on the ground to the scattering center and then to a similar receiving antenna. A correlation of total path absorption with the surface value of absolute humidity is developed, thus providing estimates of the range of absorption values in different geographic areas. Maps of average absolute humidity for the world are presented. Previous work on rain absorption is then combined with the present study to provide estimates of the radio power loss due to absorption expected to be exceeded 1 per cent of the time.

357. B. R. Bean and B. A. Cahoon, "The Use of Surface Weather Observation to Predict the Total Atmospheric Bending of Radio Rays at Small Elevation Angles," NBS Report 5082, May, 1957.

ABSTRACT

The total bending of radio rays passing completely through the earth's atmosphere has been calculated for the extremes of observed refractive index profiles at eleven United States radiosonde observation stations plus those at Fairbanks, Alaska and Truk, Caroline Islands. The significant level data of the radiosonde observations were used to allow for any possible effect of the variation of the refractive index profile from the smoothed average profiles commonly used for such studies. Even with allowance for these departures from a smooth profile it is found that the surface value of the refractivity alone may be used to predict the total bending with useful accuracy even for elevation angles of arrival or departure as small as one milliradian.

358. B. R. Bean and J. D. Horn, "On the World Wide Variations of Radio Refractivity as Derived from Standard Weather Observations," NBS Report 5083, May, 1957.

ABSTRACT

World-wide maps of the monthly mean of the surface value of the radio refractivity, N_s, are presented for the months of February and August. A map is also given of the maximum range of monthly mean values of N_s. Annual cycles of N_s are presented for each of six major climatic types. It is estimated that geographic variations of monthly mean field strengths may be as much as 25 db for identically equipped tropospheric forward scatter systems and that annual cycles may be as large as 15 db, due solely to correlation with the variation in surface refractivity.

359. "Bibliography on Tropospheric Propagation of UHF, VHF and SHF Waves," Meteorological Abstracts and Bibliography, Vol. 8, No. 8, August, 1957.

ABSTRACT

A bibliography comprised of a listing (alphabetical by author) of about 500 references to literature on the behavior of electromagnetic radiation in the UHF, VHF and SHF bands (30 to 30,000 Mc or 10 m to 1 cm) in the troposphere and lower stratosphere: i.e. any portion of the atmosphere below the ionosphere has been prepared and will be published in the August or September issue of Meteorological Abstracts and Bibliographies.

360. H. B. Janes, J. C. Stroud and M. T. Decker, "An Analysis of Propagation Measurements Made at 418 Mc Well Beyond the Horizon," NBS Report 5086, June, 1957.

ABSTRACT

This report presents the results of an analysis of transmission loss measurements made at 418 Mc over the 135-mile path from Cedar Rapids, Iowa to Quincy, Illinois during 1952 and 1953. The data consisted chiefly of continuous simultaneous recordings of signal level at several receiving antenna heights, ranging from 30 to 665 feet above ground. These data are reduced to tabulations of

hourly median values of basic transmission loss and fading range. These values, as well as the hourly difference in transmission loss observed at two heights (height-gain) are also shown plotted in scatter diagrams versus time of day for each of the 13 two-week recording periods. The medians for each recording period of all hourly values of median basic transmission loss, fading range and height-gain are plotted versus time of year to show any seasonal variation in these statistics.

The next page is 118.

II. STATUS OF PROJECTS AND FACILITIES.

A. Compilations of Data.

(a) Hourly Median Field Strengths.

Because of the large volume of radio transmission loss data available in the Tropospheric Propagation Research Section, it was decided to put all the hourly medians on IBM punch cards for future processing. This task is almost completed. It is believed that IBM methods of data processing are particularly applicable to these data.

Methods of establishing a weighting system for all of the data available are being devised, and IBM punch card methods are to be used in developing such a weighting system.

Between seven and eight hundred station-months of data which were incorporated into an equal number of graphs showing average diurnal trends during a month have been reproduced on microfilm, by request of Mr. Dickson of the Office of the Chief Signal Officer.

At the end of the calendar year 1951, the following stations were being recorded by the indicated contractors:

RECORDING AGENCY AND TRANSMITTER	FREQUENCY	PATH LENGTH
Pennsylvania State College State College, Pennsylvania		
WHDL - Olean, New York	95.7 Mc	90 Miles
WJAS - Pittsburgh, Pa.	99.7 Mc	110 Miles
WEST - Easton, Pa.	107.9 Mc	125 Miles
WTOP - Washington, D. C.	96.3 Mc	145 Miles
University of Washington Seattle, Washington		
KOIN - Portland, Oregon	101.1 Mc	140 Miles

Federal Communications
Commission

Allegan, Michigan

WENR - Chicago, Illinois	94.7 Mc	118 Miles
WKRC-TV - Cincinnati, Ohio	203.75 Mc	252 Miles
WFRO - Fremont, Ohio	99.3 Mc	109 Miles

Grand Island, Nebraska

KFOR - Lincoln, Nebraska	102.9 Mc	93 Miles
KMTU - Omaha, Nebraska	65.75 Mc	131 Miles
WOW-TV - Omaha, Nebraska	85.75 Mc	131 Miles

Ft. Lauderdale, Florida

CM21L - Havana, Cuba	102.7 Mc	240 Miles

Houston, Texas

WDSU-TV - New Orleans, La.	85.75 Mc	317 Miles

Laurel, Maryland

WABX - Harrisburg,Pa.	100.9 Mc	76 Miles
WCAU-TV - Philadelphia, Pa.	197.75 Mc	104 Miles
WIP - Philadelphia, Pa.	93.3 Mc	104 Miles
WEEU - Reading, Pa.	92.9 Mc	97 Miles
WNBF-TV - Binghampton, N.Y.	209.75 Mc	205 Miles

Livermore, California

KVCI - Chico, California	101.1 Mc	139 Miles
KARM - Fresno, California	101.9 Mc	121 Miles
KGO - San Francisco, Calif.	179.75 Mc	38 Miles

Millis, Massachusetts

KC2XAK - Bridgeport, Conn.	535.75 Mc	116 Miles
WTIC - Hartford, Conn.	96.5 Mc	80 Miles
WKTV - Utica, New York	215.75 Mc	206 Miles

Portland, Oregon

KING - Seattle, Washington	98.1 Mc	145 Miles

Powder Springs, Georgia

WCAC - Anderson, S. C.	101.1 Mc	127 Miles
WFAM - Birmingham, Ala.	215.75 Mc	122 Miles
WMRC - Greenville, S. C.	94.9 Mc	146 Miles

Santa Ana, California

KMAR - Bakersfield, Calif.	92.5 Mc	131 Miles
KFMB - San Diego, Calif.	185.75 Mc	72 Miles
KFSD - San Diego, Calif.	94.1 Mc	84 Miles

University of Texas,
Austin, Texas

KXYZ-FM - Houston, Texas	96.5 Mc	147 Miles
KPRC-TV - Houston, Texas	59.75 Mc	72 Miles
KIXL-FM - Dallas, Texas	104.5 Mc	175 Miles
WFAA-TV - Dallas, Texas	185.75 Mc	175 Miles
KLTI-FM - Longview, Texas	105.9 Mc	235 Miles
KWKH-FM - Shreveport, La.	94.5 Mc	275 Miles

University of Illinois
Urbana, Illinois

KXOK-FM - St. Louis, Mo.	93.7 Mc	147 Miles
WMBI-FM - Chicago, Ill.	95.5 Mc	126 Miles
WCSI-FM - Columbus, Ind.	93.7 Mc	139 Miles
WBKB-TV - Chicago, Ill.	71.75 Mc	127 Miles
WENR-TV - Chicago, Ill.	179.75 Mc	127 Miles
WGN-TV - Chicago, Ill.	191.75 Mc	127 Miles

United Broadcasting Co.
Cleveland, Ohio

Eight fixed recordings:

WHKC-FM - Columbus, Ohio (Horizontal, vertical, circular, and high gain receiving antennas.)	98.7 Mc	125 Miles
WCOL-FM - Columbus, Ohio	92.3 Mc	125 Miles
WJR-FM - Detroit Michigan	96.3 Mc	114 Miles
WXYZ-TV - Detroit, Michigan	179.75 Mc	114 Miles
WKBN-FM - Youngstown, Ohio	98.9 Mc	45 Miles

Two mobile recordings:

WHKC-FM - Columbus, Ohio	98.7 Mc	Twenty sampling sites.
WCOL-FM - Columbus, Ohio	92.3 Mc	Twenty sampling sites.

This work was supported in part by the National Bureau of Standards and in part by the Department of Defense. A complete summary of propagation paths for which data are available at the National Bureau of Standards will be found in NBS Report No. 2915, October 28, 1953.

Monthly summaries are made of data from each of the Cheyenne Mountain Program's recording sites, and these summaries are kept on file and used as a basic reference. Each monthly summary of recordings from a given monitoring location includes cumulative distributions of hourly medians for each of eight three-hour periods during the day, starting at midnight, a distribution of medians for all hours during the month, and in some cases cumulative distributions within each hour for extended periods of time.

(b) Terrain Profiles.

The angular distance θ is being obtained for paths where contour maps are available, and other maps are being obtained to complete as far as possible the list of terrain profiles for both within-line-of-sight and beyond-line-of-sight paths. About two thousand contour maps are presently on file; most of these have already been used in plotting available propogation path terrain profiles.

(c) Meteorological Data.

A meteorological microfilm library has been built up which contains all North American surface and constant pressure charts for the years 1946 through 1951. These data provide a ready check for unusual radio data due to unusual meteorological conditions and form the basis for correlation work with the observed transmission loss data.

Microfilm data were obtained from three Air Force bases, giving radiosonde summaries for four times a day during the years 1950 and 1951. These data are being utilized in the study of the diurnal variation of refractive index profiles.

Further consideration has been given to the use of IBM facilities of the Weather Bureau Machine Tabulating Unit at Asheville, North Carolina to make calculations necessary for radio field strength correlation studies. The Weather Bureau furnished IBM computations of (1) refractive index gradients as derived from monthly average pressure, temperature, and humidity data for each radiosonde station for the period 1946 to 1951, and (2) daily values of refractive index gradient for eighteen select U. S. stations. From these data, cumulative distributions were made up showing the statistical character of the variations of refractive index pertinent to several FM and TV propagation paths for each of several "time blocks," (see Supplement IX), and in some cases, the values of angular distance for the propagation path which would correspond to values of refractive index gradient from the surface to one kilometer exceeded one, fifty, or ninety-nine per cent of the time were computed. (Attempts to use this information in the analysis of data have not so far been successful because of the amount of work involved in refining analyses to this point.)

Emphasis is being placed on obtaining meteorological data along some of the propagation paths in the Cheyenne Mountain Experiment, including refractive index profiles measured with the Birnbaum microwave refractometer and also using the more conventional temperature and humidity elements.

B. Facilities.

(a) Mobile recording units.

Several mobile units are available for making measurements in the plains, foothills, and mountainous regions of Colorado. Equipment is being readied to continue such measurements in this region using a portable one hundred foot telescopic mast. With this equipment it is planned to demonstrate more thoroughly the behavior of some of the more recently proposed parameters for analysis and description of VHF and UHF propagation over irregular terrain.

In addition to the permanent transmitting facilities on Cheyenne Mountain, transmissions are available from a mobile unit at the top of Pikes Peak during the summer months and from Camp Carson at the base of Cheyenne Mountain.

(b) Cheyenne Mountain Experiment.

A paper entitled "Cheyenne Mountain Propagation Experiments" by A. P. Barsis, J. W. Herbstreit, and K. O. Hornberg has been approved for publication as NBS Circular No. 554. This circular describes the facilities of the National Bureau of Standards Cheyenne Mountain Field Station, the type of measurements being taken, and gives a summary of the type of data analyses being made. The circular is expected to be a basic reference concerning the unique National Bureau of Standards facilities available for tropospheric propagation measurements.

(c) Five hundred foot tower at Haswell, Colorado.

Progress in evaluating the Booker-Gordon scattering theory as a function of frequency, antenna height, and terrain is being made through the study of turbulence on a five hundred foot tower erected at Haswell, Colorado, and also with special airborne refractometer measurements made along the Cheyenne Mountain Experiment's propagation paths. At present there is a major emphasis on the design and development of temperature compensated cavities. A five hundred foot waveguide has been installed on the Haswell tower to permit refractometer installation at several levels. In February, 1954, when a 158-foot length of waveguide had been installed, refractometer cavities were installed at 15 and 158 feet, and data were obtained for the last half of February. Psychrometric data were taken over the height of the tower in order to assess the reliability of the American Instrument Company temperature and humidity elements.

(d) Airborne recordings.

In February of 1954, a two-week continuous radio recording program was sustained with five frequencies monitored at Kendrick, Karval, Haswell, and Sheridan Lake, Colorado, and at Garden City and Anthony, Kansas, this last site being four hundred miles from Cheyenne Mountain. An Air Force plane equipped with a refractometer made several spirally ascending and descending flights to obtain refractivity profiles. The plane was also flown in different regions of space across the path in an effort to determine the regions most responsible for the observed scattered fields. The analysis that has been conducted so far has revealed that our knowledge of the spatial distribution of radio field strength is not adequate to explain the scattering patterns obtained during these flights. Accordingly, field strength measurements made in August of 1954 were designed to supply the needed information. The program included transmissions from Pike's Peak on 100 and on 1046 megacycles, alternating with transmissions from Cheyenne Mountain.

C. Projects.

At present, emphasis is being given to the more rapid reduction of the large amount of data which has been taken in the past and which is expected in the future. Some of the projects proposed for the future are:

(a) The preparation of basic transmission loss versus angular distance curves for frequencies between 50 and 10,000 megacycles.

(b) The derivation of adequate definitions of antenna height over irregular terrain.

(c) A re-evaluation of basic parameters involved in the Booker-Gordon scattering theory.

(d) An investigation of polarization effects in tropospheric scattering.

(e) An investigation of path antenna gain effects. At Garden City, Kansas, two complete receiving systems on 1046 megacycles were used simultaneously, one using a dipole receiving antenna and the other a parabolic reflector; both antennas were at the same elevation above ground. This was done to obtain data on loss in antenna gain with respect to the theoretical free space gains, and to determine the effect of antenna directivity on fading rate and fading range.

(f) Trend analysis and correlation studies of radio and meteorological data. Studies of the geographical distribution of the refractivity gradient over the United States and the effects of the refractivity gradient on the observed radio transmission loss are expected to be useful in predicting the annual and geographic trends of radio transmission loss throughout the United States. Considerable progress has been made in such studies.

(g) Derivation of terrain correction factors similar to the FCC Ad Hoc Committee's M(d,f).

(h) Measurement and analysis of within-line-of-sight scattering components. A gain stable receiver with a differential amplifier was installed and operated at 100 megacycles at the Kendrick receiving site. About one week of fast speed recording showed that at the within-line-of-sight location there was considerable instantaneous variation of signal, although it was not evident on the regular recording receiver. This signal variation indicates that there is a measurable scattering component even for within-line-of-sight conditions.

(i) Study of prolonged space-wave fadeouts. An evaluation of the occurrence of prolonged space-wave fadeouts on 1046 Mc over the Cheyenne Mountain paths and on an overseas path in the San Diego, California region is considered to be important in the performance of air navigation facilities proposed for the 1000 megacycle portion of the frequency spectrum. Considerable progress has been made in determining the extent of these fadeouts on the two paths under study, and the data obtained are being used to evaluate their significance in determining the operational performance of air navigation systems operating at 1000 megacycles.

(j) Irregular terrain studies. Recently, over 120 miles of routes were traveled in making continuous irregular terrain propagation measurements of each of three VHF broadcasting stations, operating on frequencies of 59.75, 94.7 and 191.75 megacycles. In general, higher propagation loss and greater ranges of variability are associated with the foothills terrain than with the plains further east, and correlations between observations of transmission loss tend to be mostly dependent upon the degree of separation of the propagation paths and much less dependent upon differences in frequency of operation.

(k) Measurements of phase variability due to slow changes in the atmosphere, and measurements of phase instability due to random inhomogeneities in the propagation medium.

Supplement I

CORRELATION IN VHF PROPAGATION OVER IRREGULAR TERRAIN

By

R. S. Kirby and F. M. Capps
National Bureau of Standards
Boulder, Colorado

See No. 328, page 112h in the list of technical abstracts.

Supplement II

MICROWAVE PROPAGATION SURVEY IN WASHINGTON, D. C. AREA

By

K. Tritabaugh and J. H. Chisholm

Supplement II

MICROWAVE PROPAGATION SURVEY IN WASHINGTON, D. C. AREA

BY

Kenneth Tritabaugh and James H. Chisholm
National Bureau of Standards
Boulder, Colorado

Microwave propagation conditions over several paths in the Washington, D. C. area were investigated. Results of experimental tests over the particular paths are given.

The following report on a series of radio propagation tests over several proposed microwave radio relay paths has been prepared in compliance with a request from the Plant Engineering Agency, Office of the Chief Signal Officer, Department of Defense, for a preliminary propagation survey of these paths prior to the establishment of a permanent microwave radio relay system.

Discussion of this problem in an informal conference at the Pentagon, November, 1950, between Mr. J. H. Chisholm and Mr. K. F. Tritabaugh of the Central Radio Propagation Laboratory, National Bureau of Standards, and personnel of the Office of the Chief Signal Officer, Department of Defense, resulted in an agreement by this Laboratory to undertake a short-term propagation survey of the proposed paths with the assistance of military personnel. It was pointed out that the National Bureau of Standards had 4500-5000 Mc AN/TRC-6 microwave radio relay equipment suitable for this purpose and immediately available but that results from this equipment operating in the 4500-5000 Mc range would not be directly comparable to that expected from the proposed permanent installations operating near 2000 Mc with regards to path clearance and fading rates and fading ranges. Since procurement of 2000 Mc equipment and modification for recording would have required considerable time, it was agreed to undertake these tests with the 4500-5000 Mc equipment on a short-term basis as a useful guide for future installations. It was further agreed that these tests would be limited to a few weeks on each path in order to complete the survey as rapidly as possible although seasonal variations would not be accurately represented.

Mr. K. F. Tritabaugh of the Laboratory was assigned to devote full time to this survey and with the excellent assistance and cooperation of military personnel, established experimental microwave terminals and recorded radio field intensity over the following paths:

6 February-19 February, 1951	-	Quirauk Mt. to Sugar Loaf Mt.
28 February-11 March, 1951	-	Sugar Loaf Mt. to Silver Hill
20 March -24 March, 1951	-	Ft. Meade to Silver Hill
5 April -12 April, 1951	-	Silver Hill to La Plata, Md.

Attached Figs. 1 through 4 show the profiles of these four paths with earth curvature corrected for the refraction of radio waves in a standard atmosphere. The first Fresnel zone for a wavelength of 6.9 centimeters (4350 Mc) is outlined by broken lines on these profiles. Complete clearance of this first Fresnel zone by intervening topography is considered the minimum condition for a satisfactory microwave path by most commercial radio relay system engineers. It should be noted that tree foliage in the Maryland Coastal Region often reaches heights of 80-100 feet and is not shown on these ground profiles. The effect of obstructions by tree foliage will be more pronounced near the terminals since the proportion of the Fresnel zone obscured by tree foliage may become large as the zone decreases in area near the terminals. The vertical width of the first Fresnel zone is proportional to the square root of the wavelengths ratio or inversely proportional to the square root of the frequency ratio (i.e., for 2000 Mc, the vertical dimensions would be $1/\sqrt{\frac{2000}{4350}}$ or 1.48 times greater than shown).

Under normal propagation conditions and with rough intervening terrain a path loss of 6 db referred to the free space value would be caused by obscuring one half of the vertical width of the first Fresnel zone. On this basis, a 2000 Mc system should be only a few decibels poorer than 4350 Mc for all four paths as shown under standard tropospheric conditions. Experience has shown that fading rates and fading ranges as a function of frequency as caused by varying non-standard meteorological conditions are complex in nature. In general, the fading rates and range of fades appears to increase with frequency, although precise quantitative data for a specific climatological area are too inadequate to allow a firm conclusion. The range of fading, rapidity of fading, and the median field strength of microwaves over extended distances show pronounced diurnal and seasonal variations. Experience with microwave radio relay systems in the Maryland-Virginia regions indicates that the summer median fields will be higher than winter and early spring values but that fading will also be more pronounced, particularly in the evening hours. However, an increase in path loss in summer months may be caused by the increase in opaqueness to microwaves of the tree foliage in full leaf and particular attention should be directed to potential summer tree foliage obstructions near the terminals, as mentioned earlier. It is recommended that maximum use of towers at each terminal be made to clear nearby foliage.

An analysis of the hourly median field strengths as shown in Figs. 5-8, and in the accompanying tables, indicates that all four paths are within a few db of the free space value (i.e., closely comparable to paths with an unobstructed first Fresnel zone) if one ignores the tropospheric variations which are of the order of ten decibels. A definite diurnal cycle is present on most days and will probably be more pronounced in the summer months. The losses recorded on the Quirauk to Sugar Loaf path on February 7, are believed to be caused by snow and ice on the antenna system rather than tropospheric propagation effects. It should be noted that all data is referred to free space as zero decibels and can be calculated in the following manner:

$$P_r = \frac{P_t}{4\pi R^2} G_t G_r \frac{\lambda^2}{4\pi}$$

P_r = Power received by receiving antenna in watts under free space conditions.

P_t = Power delivered to the transmitting antennas in watts.

G_t = Numerical power gain of transmitting antenna relative to an isotropic antenna.

G_r = Numerical power gain of receiving antenna relative to an isotropic antenna

R = Distance between terminals in meters.

λ = Wavelength in meters.

Note: RF transmission line losses are not included in these calculations, but are included in the threshold levels.

The threshold signal levels of the AN/TRC-6 radio relay for all paths are shown as actually measured. The threshold is 42 db or more below free space for the power radiated, antenna gains, receiver sensitivity, and transmission line losses of this particular set, and each specific path distance. The threshold is defined in this report as the minimum signal level that intelligible conversation can be maintained with the AN/TRC-6 equipment. From prior experience with the AN/TRC-6, it was found that this level is approximately six decibels above noise for a single circuit although a completely quiet circuit requires a signal ten db above noise.

From these results, it is evident that AN/TRC-6 equipment would furnish reliable communications over these single links with approximately 40 db margin for variation. This margin should be adequate for all but extremely severe tropospheric variations and it is believed that comparable commercial microwave systems would perform satisfactorily. It is recommended that an on-the-spot survey of tree foliage height near each terminal or other critical points along the path be made in the summer months and added to the ground profile.

It is hoped that this brief survey report will serve as a useful guide for the permanent microwave installation. The National Bureau of Standards will be happy to provide further details on these tests upon request.

SUGAR LOAF MT. TO QUIRAUK MT.

Relative to free space.

Date		Time	Max.	Min.	Med.
February 6		12-1 pm	+ .7 db	- .1 db	+ .5 db
		1:20-3	Power Off		
		3-4	+1.7	+ .4	+ .6
		4-5	+1.9	+ .6	+1.6
		5-6	+1.8	+ .5	+1.5
		6-7	+1.6	+1.6	+1.6
		7-8	+1.6	+1.6	+1.6
		8-9	+1.8	+ .8	+1.6
		9-10	+2.4	+ .6	+1.6
		10-11	+2.5	+1.1	+1.6
		11-12	+2.5	-4.4	+2.2
February 7		12-1	-3.6	-9.4	-7.4
		1-2	-3.7	-7.4	-4.6
		2-3	+ .6	- .4	+ .1
		3-4	- .4	- .4	- .4
		4-5	- .4	- .4	- .4
		5-6	- .4	-1.4	- .9
		6-7	- .9	- .9	- .9
		7-8	- .4	-2.4	-1.4
	(	8-9	- .4	-4.4	-2.5
	(	9-10	-1.9	-4.4	-2.9
Heavy	(	10-11	-1.4	-3.1	-1.9
Snow	(	11-12	-1.4	-10.4	-3.4
	(	12-1	-1.4	-13.4	-8.4
	(	1-2	-10.4	-13.4	-11.4
	(	2-3	-8.4	-13.4	-10.4
		3-4	-8.4	-10.4	-9.4
		4-5	-8.4	-8.4	-8.4
		5-6	-8.4	-10.4	-9.4
		6-7	-7.9	-9.4	-8.7
		7-8	-8.4	-10.4	-9.4
		8-9	-7.4	-9.4	-8.4
		9-10	-7.4	-8.4	-7.9
		10-11	-7.4	-7.4	-7.4
		11-12	- .4	-13.4	-7.4

Date	Time	Max.	Min.	Med.
February 8	12-1	-6.4 db	-10.4 db	-9.9 db
	1-2	-1.4	-7.4	-3.9
	2-3	-2.4	-9.4	-7.4
	3-4	-1.9	-7.9	-6.9
	4-5	-6.4	-7.4	-6.9
	5-6	-6.4	-6.4	-6.4
	6-7	-5.9	-6.4	-6.2
	7-8	-5.4	-6.4	-5.9
	8-9	-4.4	-6.4	-4.9
	9-10	- .4	-5.4	-3.9
	10-11	-1.4	-1.4	-1.4
	11-12	- .4	-3.4	-1.4
	12-4	Calibrate and power off		
	4-5	+ .5	- .4	+ .1
	5-6	+ .6	+ .1	+ .4
February 9	2-3 pm	-1.1	-2.1	-1.6
	3-4	- .6	-1.1	- .9
	4-5	- .1	-2.1	-1.1
	5-6	- .1	- .1	- .1
	6-7	- .1	- .1	- .1
	7-8	- .1	- .1	- .1
	8-9	+ .4	- .1	0
	9-10	- .1	- .1	- .1
	10-11	+ .9	- .1	+ .4
	11-12	+ .9	- .1	+ .1
February 10	12-1	+ .9	- .8	- .1
	1-2	+ .9	- .8	+ .4
	2-3	+ .2	- .1	+ .1
	3-4	+ .5	- .1	+ .2
	4-5	+ .4	- .3	- .1
	5-6	+ .4	- .1	+ .3
	6-7	+ .9	+ .2	+ .4
	7-8	+ .4	- .2	+ .3
	8-9	+ .9	- .6	- .1
	9-10	+ .9	- .1	+ .4
	10-11	- .1	-2.1	-1.1
	11-4	Off for repairs Power troubles at Sugar Loaf		

Date	Time	Max.	Min.	Med.
February 11	3-4 pm	-1.3 db	-3.3 db	-3.1 db
	4-5	-2.3	-2.3	-2.3
	5-6	-1.1	-2.3	-1.8
	6-7	-1.8	-1.8	-1.8
	7-8	- .5	-1.8	-1.3
	8-9	-1.3	-1.3	-1.3
	9-10	- .3	-1.7	-1.3
	10-11	+ .2	-1.3	-1.0
	11-12	- .9	-1.9	-1.3
February 12	12-1	-1.3	-2.3	-1.4
	1-2	- .8	-1.8	-1.3
	2-3	-1.0	-2.4	-1.8
	3-4	- .7	-3.3	-2.5
	4-5	-1.9	-3.8	-3.0
	5-6	-2.8	-5.8	-4.7
	6-7	-2.8	-5.0	-3.2
	7-8	-2.5	-3.8	-2.9
	8-9	-2.3	-4.8	-2.8
	9-10	- .3	-2.8	-2.3
	10-11	- .8	-2.3	-1.8
	11-12	-1.0	-2.3	-1.9
	12-2	Calibrating		
	2-3	+1.0	-1.5	0
	3-4	+ .5	+ .5	+ .5
	4-5	+ .5	+ .5	+ .5
	5-6	+ .8	+ .3	+ .6
	6-7	+ .8	- .3	+ .1
	7-8	+1.3	+ .3	+ .5
	8-9	+1.5	+ .5	+1.0
	9-10	+1.5	+1.5	+1.5
	10-11	+1.0	+1.0	+1.0
	11-12	+2.0	+1.0	+1.1
February 13	12-1	+2.0	+ .5	+1.5
	1-2	+3.2	- .5	+1.5
	2-3	+2.2	0	+1.5
	3-4	+2.0	- .3	+ .5
	4-5	+1.5	+ .5	+1.0
	5-6	+1.5	- .5	+ .3
	6-7	+1.5	- .5	+ .5

Date	Time	Max.	Min.	Med.
February 13	7-8	+1.5 db	- .3 db	+ .4 db
	8-2	Power Off		
	2-3	-1.5	-3.1	-1.6
	3-4	-2.0	-2.0	-2.0
	4-5	-2.0	-2.0	-2.0
		Power Off		
February 14	2-3 pm	Equipment		
	3-4	trouble		
	4-5	+ .4	- .5	- .2
	5-6	+1.0	0	+ .5
	6-7	+1.0	+1.0	+1.0
	7-8	+1.0	+1.0	+1.0
	8-9	+1.0	+ .5	+ .8
	9-10	+1.0	+ .5	+ .8
	10-11	+ .5	-6.5	- .3
	11-12	+1.3	0	+ .6
February 15	12-1	+2.0	+1.5	+1.7
	1-2	+1.6	+1.3	+1.5
	2-3	+2.4	+1.3	+1.6
	3-4	+2.5	+1.6	+1.9
	4-5	+2.6	+2.2	+2.5
	5-6	+3.0	+2.6	+2.8
	6-7	+3.0	+2.3	+2.6
	7-8	+2.5	+2.5	+2.5
	8-9	+2.5	+1.3	+2.2
	9-10	+2.5		+1.5
	10-11	+3.7		+3.0
	11-12	+2.7		+2.5
	12-1			-1.0
	1-2			-1.6
	2-3	Calibrate		
	3-4			-2.5
	4-5			-2.5
	5-6			-2.5
	6-7			-2.5
	7-8			-2.5
	8-9			-1.9
	9-10			-1.7
	10-11			-2.2
	11-12			-1.7

Date	Time	Max.	Min.	Med.
February 16	12-1			-1.5 db
	1-4			-1.5
	2-3			-1.5
	3-4			-1.0
	4-5			- .5
	5-6			+1.0
	6-7			+1.6
	7-8			+1.0
	8-9			+1.5
	9-10			+1.7
	10-11			+2.0
	11-1	Calibrate		
	1-2			-1.0
	2-3			-1.0
	3-4			-1.0
	4-5			-1.0
	5-6			- .7
	6-7			- .5
	7-8			- .5
	8-9			- .5
	9-10			- .5
	10-11			- .5
	11-12			-1.0
February 17	12-1			-1.0
	1-2			-1.5
	2-3			-2.4
	3-4			-3.0
	4-5			-8.0
	5-6			-10.0
	6-7			-12.0
	7-8			-7.5
	8-9			-5.5
	9-10			-5.5
	10-11			-5.5
	11-12			-4.5
	12-1			-4.0
	1-2			-1.8
	2-3			-2.5

Date	Time	Max.	Min.	Med.
February 17	3-4			-2.5 db
	4-5			-4.0
	5-6			-4.0
	6-7			-3.0
	7-8			-2.5
	8-9			-2.0
	9-10			-2.0
	10-11			-2.0
	11-12			-2.0
February 18	12-1			-1.5
	1-2			-1.0
	2-3			-1.0
	3-4			-1.0
	4-5			-1.0
	5-6			-1.0
	6-7			-1.0
	7-8			-1.0
	8-9			-1.0
	9-10			-1.0
	10-11	Calibrate		
	11-12			-1.0
	12-2	Power Off		
	2-3			-2.6
	3-4			-2.5
	4-5			-2.5

Date	Time	Max.	Min.	Med.
February 18	5-6			-2.5
	6-7			-2.5
	7-8			-2.8
	8-9			-2.3
	9-10			-2.0
	10-11			-2.0
	11-12			-2.0
February 19	12-1			-2.8
	1-2			-3.0
	2-3			-1.5
	3-4			-1.5
	4-5			-2.0
	5-6			-2.1
	6-7			-1.5
	7-8			-1.2
	8-9			-1.2
	9-10			-2.2
	10-11			-2.5
	11-12			-3.0
	12-1			-3.7
	1-2			-4.3
	2-3			-3.8
	3-4			-2.0
	4-5			-1.7
	5-6			-1.5
	6-7			-1.5
	7-8			-1.5
	8-9			-1.5
	9-10			-1.5
	10-11			-1.5
	11-12			-1.5
February 20	12-1			- .7
	1-2			- .5
	2-3			- .5
	3-4			- .5
	4-5			-1.0
	5-6			-1.0

SUGAR LOAF MT. TO SILVER HILL

Date	Time	Med.
February 28	3-4 pm	-7.2 db
	4-5	-7.2
	5-6	-6.9
	6-7	-6.9
	7-8	-5.9
	8-9	-5.9
	9-10	-6.3
	10-11	-6.3
	11-12	-6.5
March 1	Mid-1	-5.7
	1-2	-5.7
	2-3	-5.8
	3-4	-5.6
	4-5	-5.8
	5-6	-6.2
	6-7	-7.5
	7-8	-11.4
	8-9	-11.0
	9-10	Power
	10-11	-14.2
	11-12	-10.9
	Noon-1	-9.6
	1-2	-9.0
	2-3	-9.7
	3-4	-7.2
	4-5	-7.1
	5-6	-7.3
	6-7	-7.4
	7-8	-7.2
	8-9	-7.1
	9-10	-6.8
	10-11	-6.6
	11-12	-4.7
March 2	Mid-1	-8.2
	1-2	-7.9
	2-3	-19.2

Date	Time	Med.
March 2	3-4	-15.2 db
	4-5	-14.2
	5-6	-12.2
	6-7	-11.2
	7-8	-9.7
	8-9	-8.3
	9-10	-6.2
	10-11	Cal.
	11-12	Cal.
	Noon-1	-4.0
	1-2	-4.0
	2-3	-3.9
	3-4	-3.7
	4-5	-2.7
	5-6	-2.2
	6-7	-2.6
	7-8	-1.2
	8-9	-1.7
	9-10	-2.8
	10-11	-3.0
	11-12	-3.0
March 3	Mid-1	-2.8
	1-2	-2.2
	2-3	-2.1
	3-4	-2.4
	4-5	-1.4
	5-6	-1.3
	6-7	-1.5
	7-8	-2.0
	8-9	-2.1
	9-10	-1.6
	10-11	Cal.
	11-12	Cal.
	Noon-1	-3.2
	1-2	-3.2
	2-3	-3.4
	3-4	-6.2
	4-5	-7.4

Date	Time	Med.
March 3	5-6	-9.2 db
	6-7	-8.7
	7-8	-9.9
	8-9	-8.9
	9-10	-8.8
	10-11	-11.3
	11-12	-9.7
March 4	Mid-1	-8.9
	1-2	-7.9
	2-3	-7.7
	3-4	-7.6
	4-5	-6.4
	5-6	-6.5
	6-7	-6.4
	7-8	-7.5
	8-9	-7.3
	9-10	-7.4
	10-11	-6.9
	11-12	Cal.
	Noon-1	-6.4
	1-2	Power
	2-3	Power
	3-4	-6.4
	4-5	-5.8
	5-6	-5.4
	6-7	-5.3
	7-8	-5.0
	8-9	-4.8
	9-10	-5.4
	10-11	-5.0
	11-12	-4.5
March 5	Mid-1	-5.4
	1-2	-5.4
	2-3	-4.4
	3-4	-4.6
	4-5	-6.4
	5-6	-8.4

Power Off

Date	Time	Med.
March 5	11-12	-5.8db
	Noon-1	-5.5
	1-2	-6.0
	2-3	-6.0
	3-4	-6.1
	4-5	-6.2
	5-6	-5.0
	6-7	-3.6
	7-8	-1.8
	8-9	-1.8
	9-10	-2.6
	10-11	-3.8
	11-12	-3.7
March 6	Mid-1	-7.1
	1-2	-12.2
	2-3	-5.6
	3-4	-1.8
	4-5	-5.2
	5-6	-6.6
	6-7	-6.7
	7-8	-3.4
	8-9	- .8
	9-10	-1.1
	10-11	-3.0
	11-12	-5.9
	Noon-1	-6.3
	1-2	-5.9
	Power off	
March 7	Noon-1	-5.9
	1-2	-6.6
	2-3	-6.6
	3-4	-6.6
	4-5	-6.6
	5-6	-6.4
	6-7	-4.9
	7-8	-4.0

Date	Time	Med.
March 7	8-9	-5.1 db
	9-10	-4.3
	10-11	-5.0
	11-12	-3.6
March 8	Mid-1	-3.6
	1-2	-5.5
	2-3	-3.3
	3-4	-4.0
	4-5	-6.7
	5-6	-4.7
	6-7	-5.5
	7-8	-6.6
	8-9	-4.2
	9-10	-3.4
	10-11	-5.3
	11-12	Cal.
	Noon-1	-4.7
	1-2	-4.7
	2-3	-5.8
	3-4	-5.8
	4-5	-5.3
	5-6	-5.6
	6-7	-4.4
	7-8	-2.6
	8-9	-1.6
	9-10	-2.7
	10-11	-2.9
	11-12	-2.7
March 9	Mid-1	-3.3
	1-2	-3.3
	2-3	-3.2
	3-4	-3.2
	4-5	-3.2
	5-6	-3.2
	6-7	-3.2
	7-8	-2.4
	8-9	-3.6
	9-10	-4.7

Date	Time	Med.
March 9	10-11	-5.2 db
	11-12	-5.3
	Noon-1	-5.3
	1-2	-5.4
	2-3	Cal.
	3-4	-4.4
	4-5	-4.2
	5-6	-3.7
	6-7	-2.9
	7-8	-2.7
	8-9	-2.3
	9-10	-1.7
	10-11	-2.0
	11-12	-1.7
March 10	Mid-1	-1.7
	1-2	-1.6
	2-3	-1.5
	3-4	-1.2
	4-5	- .2
	5-6	- .4
	6-7	- .3
	7-8	- .6
	8-9	- .9
	9-10	-1.8
	10-11	-2.3
	11-12	Cal.
	Noon-1	-5.2
	1-2	-4.7
	2-3	-4.6
	3-4	-4.7
	4-5	-5.0
	5-6	-4.2
	6-7	-3.4
	7-8	-3.1
	8-9	-3.1
	9 -10	-3.2
	10-11	-3.2
	11-12	-3.2

Date	Time	Med.
March 11	Mid-1	-3.2 db
	1-2	-2.7
	2-3	-2.7
	3-4	-2.4
	4-5	-2.3
	5-6	-2.5
	6-7	-2.5
	7-8	-2.5
	8-9	-3.5
	9-10	-3.5
	10-11	-4.2
	11-12	Cal.
	Noon-1	-4.4
	1-2	-4.4
	2-3	-4.4
	3-4	Power
	4-5	-3.7
	5-6	-3.2
	6-7	-2.4
	7-8	-1.7
	8-9	-1.4
	9-10	-1.7
	10-11	-1.8
	11-12	-2.1
March 12	Mid-1	-1.3
	1-2	-1.3
	2-3	-1.2
	3-4	-1.1
	4-5	- .6
	5-6	- .6
	6-7	- .6
	7-8	-1.2
	8-9	-2.0
	9-10	-3.1

FT. MEADE TO SILVER HILL

Threshold =-46 db

Date	Time	Med.
March 20	Noon-1	-4.4 db
	1-2	-3.9
	2-3	-4.9
	3-4	-4.9
	4 -5	-4.9
	5-6	-4.5
	6-7	-3.1
	7-8	-2.3
	8-9	-1.9
	9-10	-1.7
	10-11	-1.5
	11-12	-3.5
March 21	Mid-1	-2.4
	1-2	+1.1
	2-3	+5.1
	3-4	- .9
	4-5	-3.5
	5 -6	- .1
	6-7	0
	7-8	+ .3
	8-9	- .5
	9-10	-3.3
	10-11	-5.1
	11-12	-4.9
	Noon-1	-4.9
	1-2	-4.7
	2-3	Power
	3-4	+ Cal.
	4-5	-1.6
	5-6	-1.8
	6-7	-1.8
	7-8	-1.6
	8-9	-2.0
	9-10	-3.5
	10-11	Power
	11-12	Power

Date	Time	Med.
March 22	Mid-1	Power
	1-2	-2.1 db
	2-3	- .9
	3-4	+ .6
	4-5	+4.4
	(Power)	
	3-4 pm	-3.7
	4-5	-4.0
	5-6	-3.5
	6-7	-2.7
	7-8	-2.3
	8-9	- .5
	9-10	-1.0
	10-11	-2.3
	11-12	-1.1
March 23	Mid-1	+1.8
	1-2	- .5
	2-3	-1.0
	3-4	0
	4-5	+1.8
	5-6	+1.8
	6-7	+ .3
	7-8	0
	8-9	-3.5
	9-10	-3.2
	10-11	-2.9
	11-12	-3.2
	Noon-1	-3.2
	1-2	-3.5
	2-3	-3.5
	3-4	-3.5
	4-5	-3.4
	5-6	-2.8
	6-7	-2.9
	7-8	-3.0
	8-9	-3.0

Date	Time		Med.
March 23	9-10		-3.0 db
	10-11		-3.8
	11-12		-4.0
March 24	Mid-1		-4.4
	1-2		-4.4
	2-3		-4.5
	3-4		-4.5
	4-5		-4.2
	5-6		-4.2
	6 -7		-3.8
	7-8		-2.0
	8-9		-2.2
	9-10		-2.3
	10-11		Cal.
	11-12		-1.0
	Noon-1		-2.8
	1-2		-3.5
	2 -3		-3.5
	3-4		-3.5
	4-5		-3.9
		Paper Jammed	
March 25	11-12		-4.2
	Noon-1		-4.7
	1-2		-4.9
	2-3		-4.5
	3-4		-4.7
	4-5		-4.5
	5-6		-4.2
	6 -7		-2.7
	7-8		-1.8
	8 -9		- .5
	9-10		-1.3
	10-11		-1.6
	11-12		-1.7

Date	Time	Med.
March 26	Mid-1	-2.2
	1-2	-2.8
	2-3	-2.9
	3-4	-2.9
	4-5	-2.5
	5-6	-2.5
	6-7	- .9
	7-8	-3.2
	8-9	-4.5
	9-10	-5.0
	10-11	-5.5
	11-12	Check Ant.
	Noon-1	-4.7
	1-2	-4.5
	2-3	Cal.
	3-4	-4.0
	4-5	-4.0
	5-6	-3.5
	6-7	-2.8
	7-8	-1.5
	8-9	-1.5
	9-10	-1.5
	10-11	-1.0
	11-12	-1.0
March 27	Mid-1	-1.2
	1-2	-1.0
	2-3	-2.0
	3-4	+1.5
	4-5	+4.0
	5-6	+3.0
	6-7	+1.0
	7-8	-1.5
	8-9	-1.7
	9-10	-2.3

SILVER HILL TO LA PLATA

Threshold = -48 db

Date	Time	Med.
April 5	3-4 pm	-6.5 db
	4-5	-6.5
	5-6	-6.0
	6-7	-4.5
	7-8	-3.2
	8-9	-2.5
	9-10	-2.5
	10-11	-3.5
	11-12	-4.2
April 6	Mid-1	-2.0
	1-0	+1.0
	2-3	+2.5
	3-4	+2.0
	4-5	0
	5-6	-1.6
	6-7	-4.0
	7-8	-6.0
	8-9	-7.0
	9-10	-6.4
	10-11	Power
	11-12	Off
	Noon-1	-8.0
	1-2	Cal.
	2-3	-5.0
	3-4	-5.5
	4-5	-3.6
	5-6	-3.7
	6-7	-2.1
	7-8	+ .2
	8-9	+2.2
	9-10	0
	10-11	-1.0
	(Power Trouble)	
April 10	3-4 pm	-6.0
	4-5	-5.6

Date	Time	Med.
April 10	5-6	-5.0 db
	6-7	-2.2
	7-8	+ .5
	8-9	0
	9-10	+2.0
	10-11	+3.0
	11-12	+4.0
April 11	Mid-1	+2.0
	1-2	+ .7
	2-3	+1.5
	3-4	-1.0
	4-5	-2.0
	5-6	0
	6-7	0
	7-8	-3.0
	8-9	-6.0
	9-10	-6.0
	10-11	-7.0
	11-12	-6.8
	Noon-1	-5.5
	1-2	-4.2
	2-3	Cal.
	3-4	-3.5
	4-5	-2.9
	5-6	-1.1
	6-7	- .8
	7-8	+ .6
	8-9	+ .1
	9-10	+ .6
	10-11	+ .5
	11-12	+ .6
April 12	Mid-1	-1.0
	1-2	-7.0
	2-3	-2.1
	3-4	-3.3
	4-5	-3.5
	Power Off	

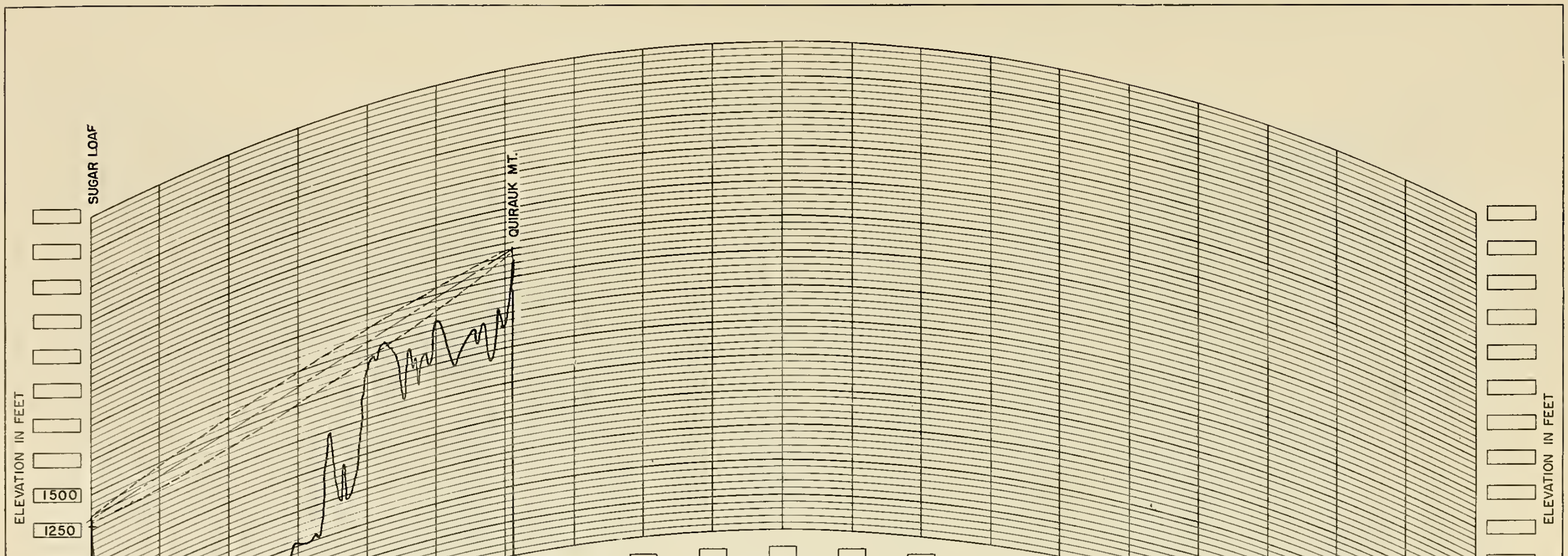


FIG. I

PROFILE CHART

(4/3 EARTH RADIUS USED TO CORRECT FOR STANDARD ATMOSPHERE REFRACTION)

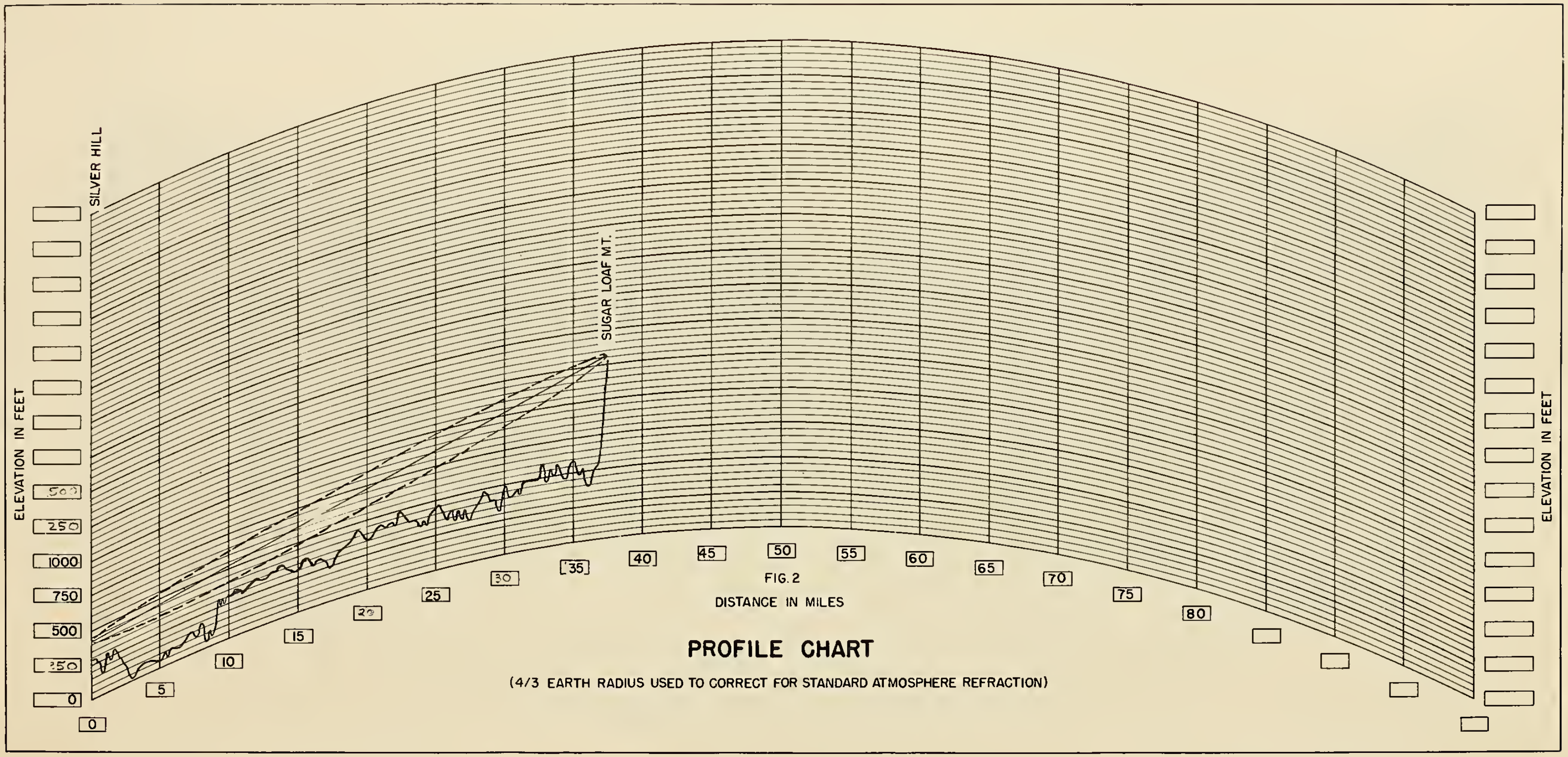


FIG. 2

PROFILE CHART

(4/3 EARTH RADIUS USED TO CORRECT FOR STANDARD ATMOSPHERE REFRACTION)

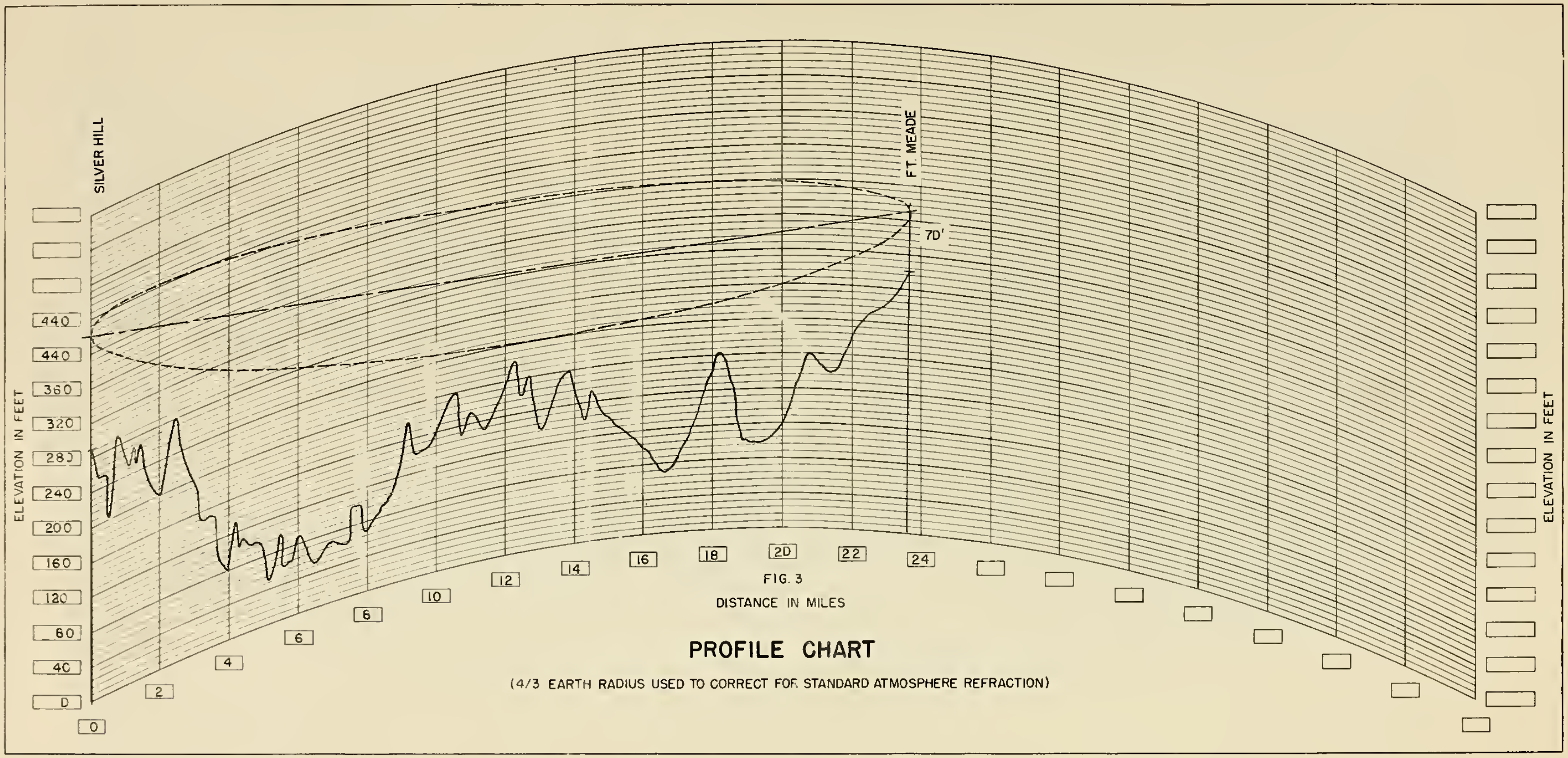


FIG. 3

PROFILE CHART

(4/3 EARTH RADIUS USED TO CORRECT FOR STANDARD ATMOSPHERE REFRACTION)

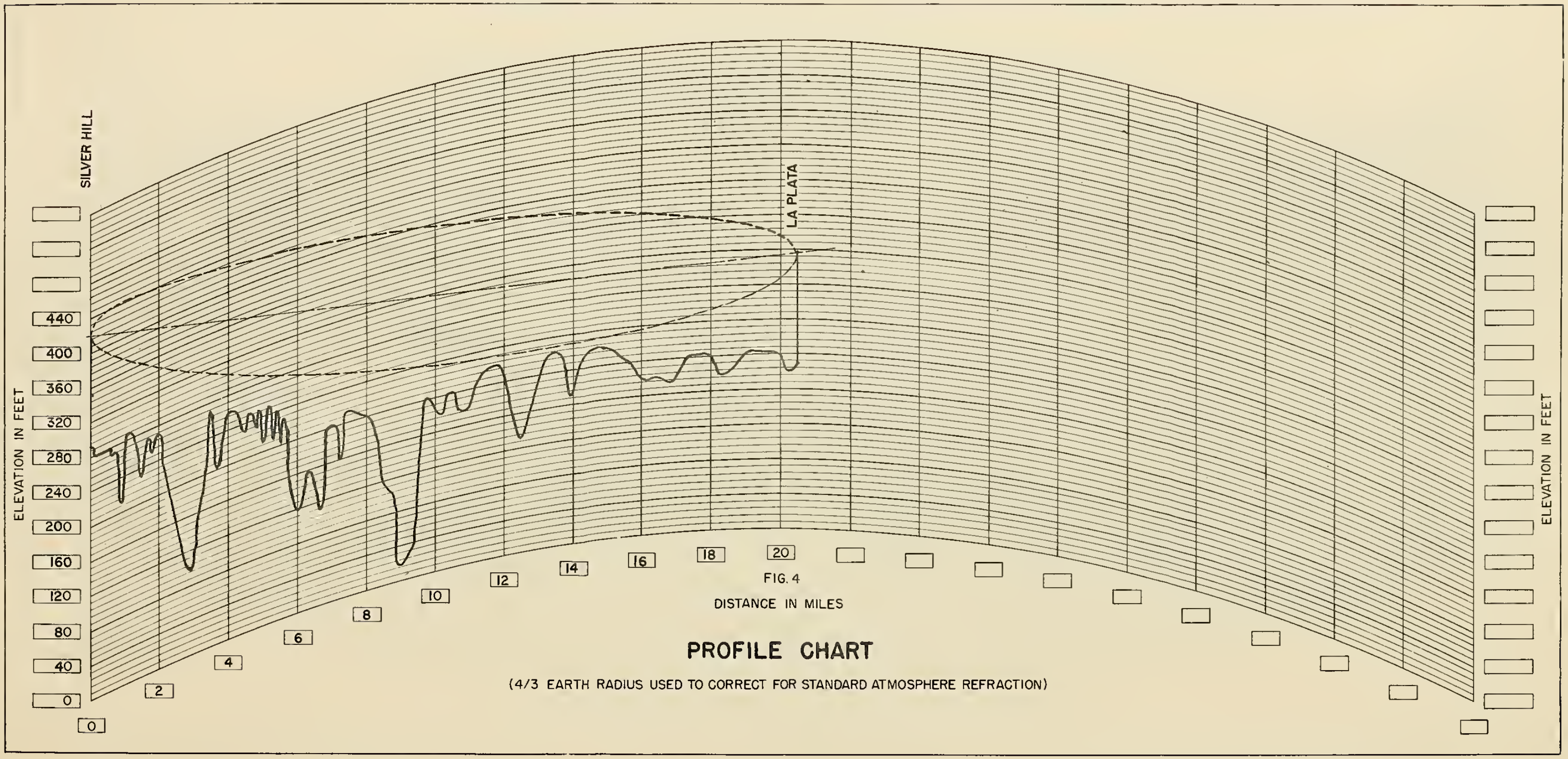


FIG. 4

PROFILE CHART

(4/3 EARTH RADIUS USED TO CORRECT FOR STANDARD ATMOSPHERE REFRACTION)

QUIRAUK MT. TO MT. SUGAR LOAF

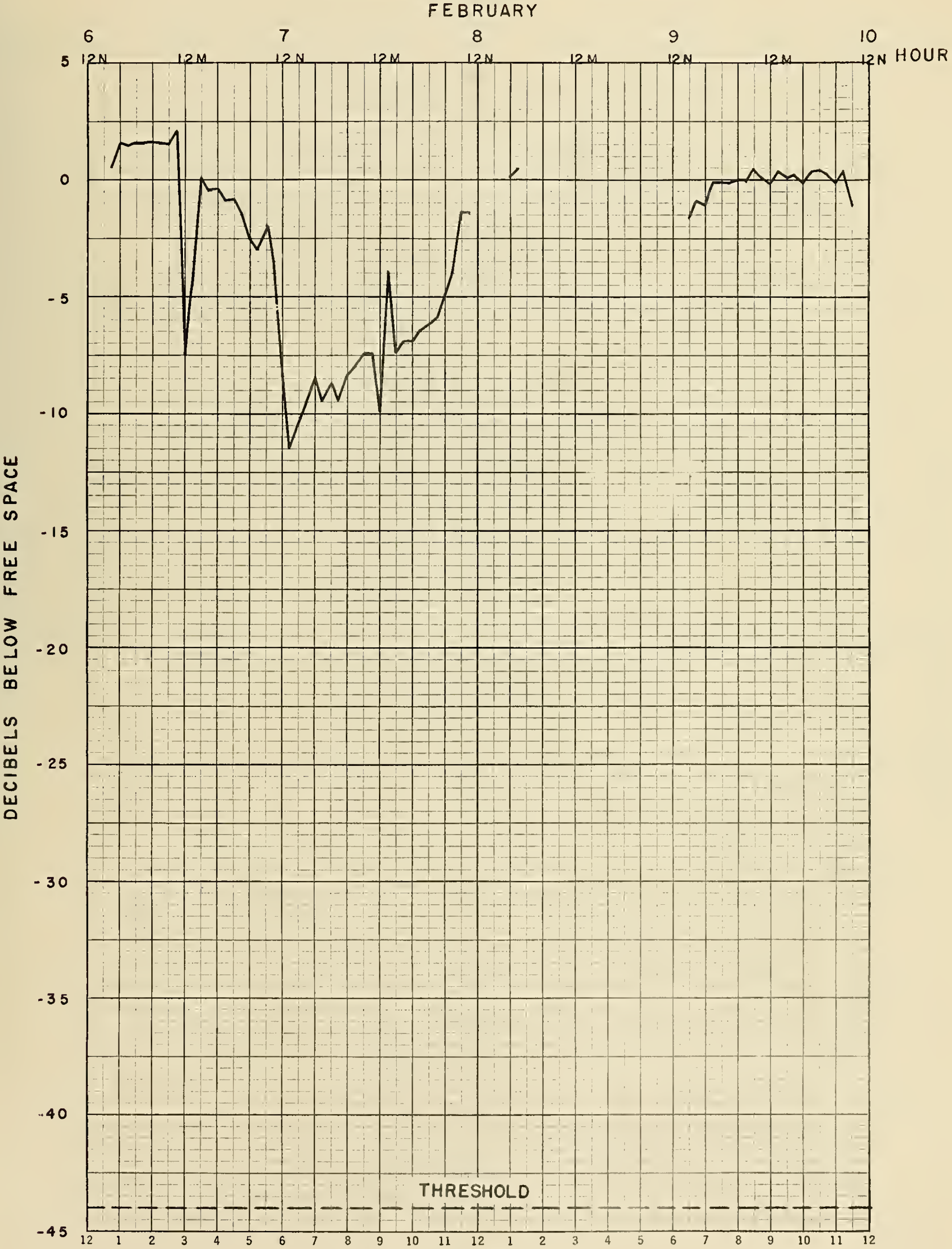


FIG. 5a.

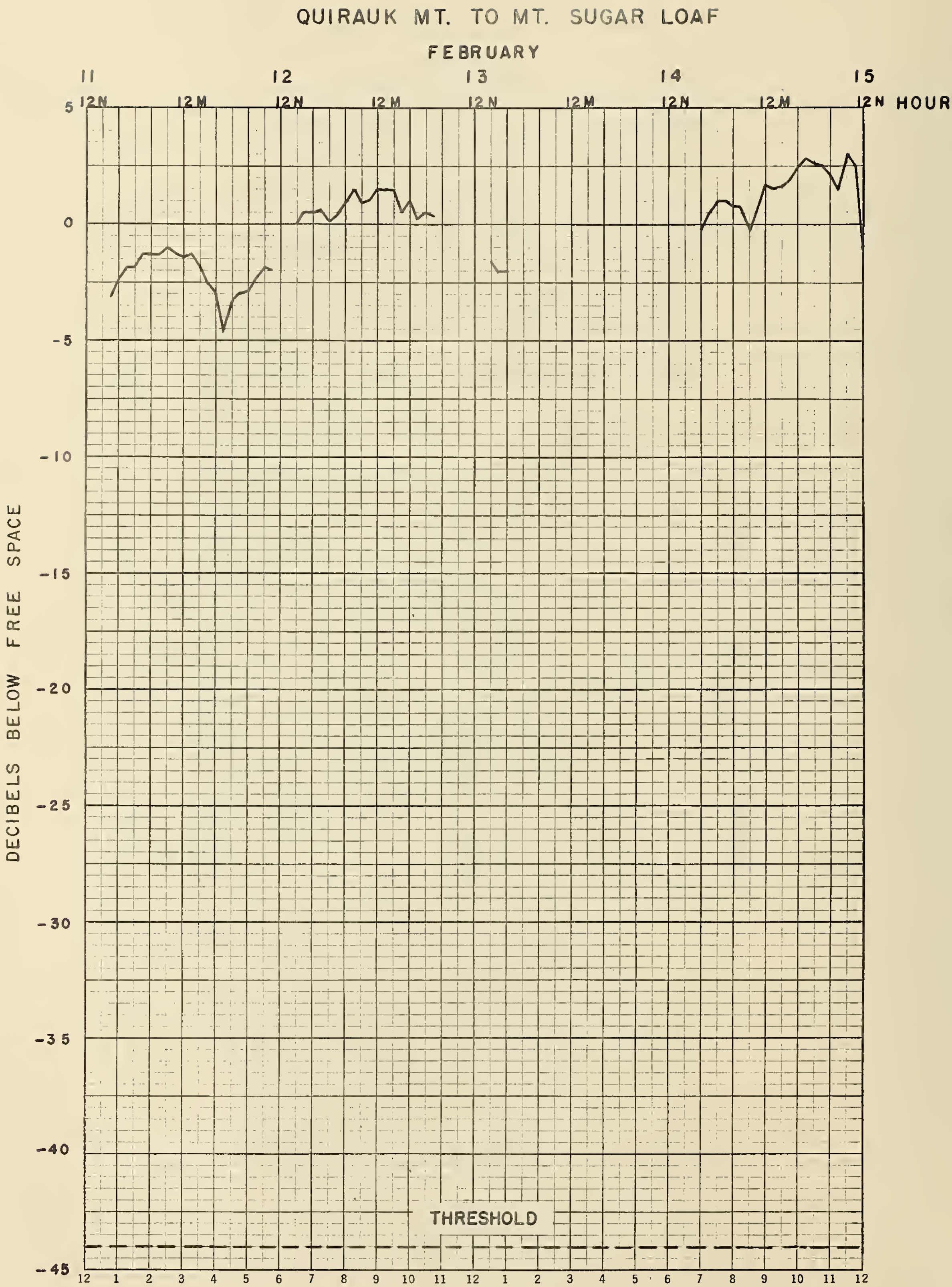
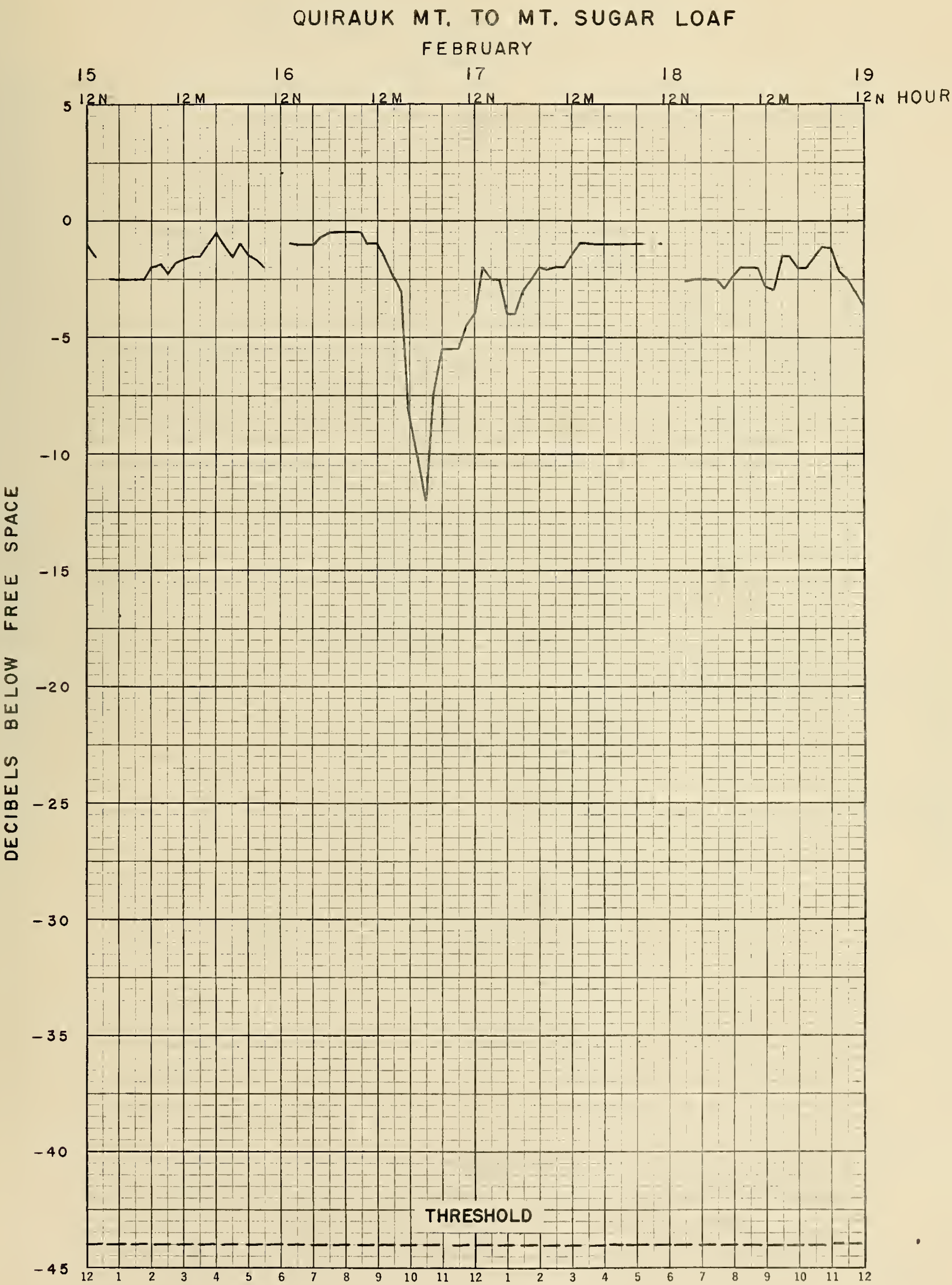

QUIRAUK MT. TO MT. SUGAR LOAF
FEBRUARY
11
12
13
14
15
12N
12M
HOUR
DECIBELS BELOW FREE SPACE
5
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
THRESHOLD
12 1 2 3 4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12

FIG.5b.



QUIRAUK MT. TO MT. SUGAR LOAF
FEBRUARY
15
16
17
18
19
12N
12M
HOUR
DECIBELS BELOW FREE SPACE
5
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
THRESHOLD
12
1
2
3
4
5
6
7
8
9
10
11

FIG.5c.

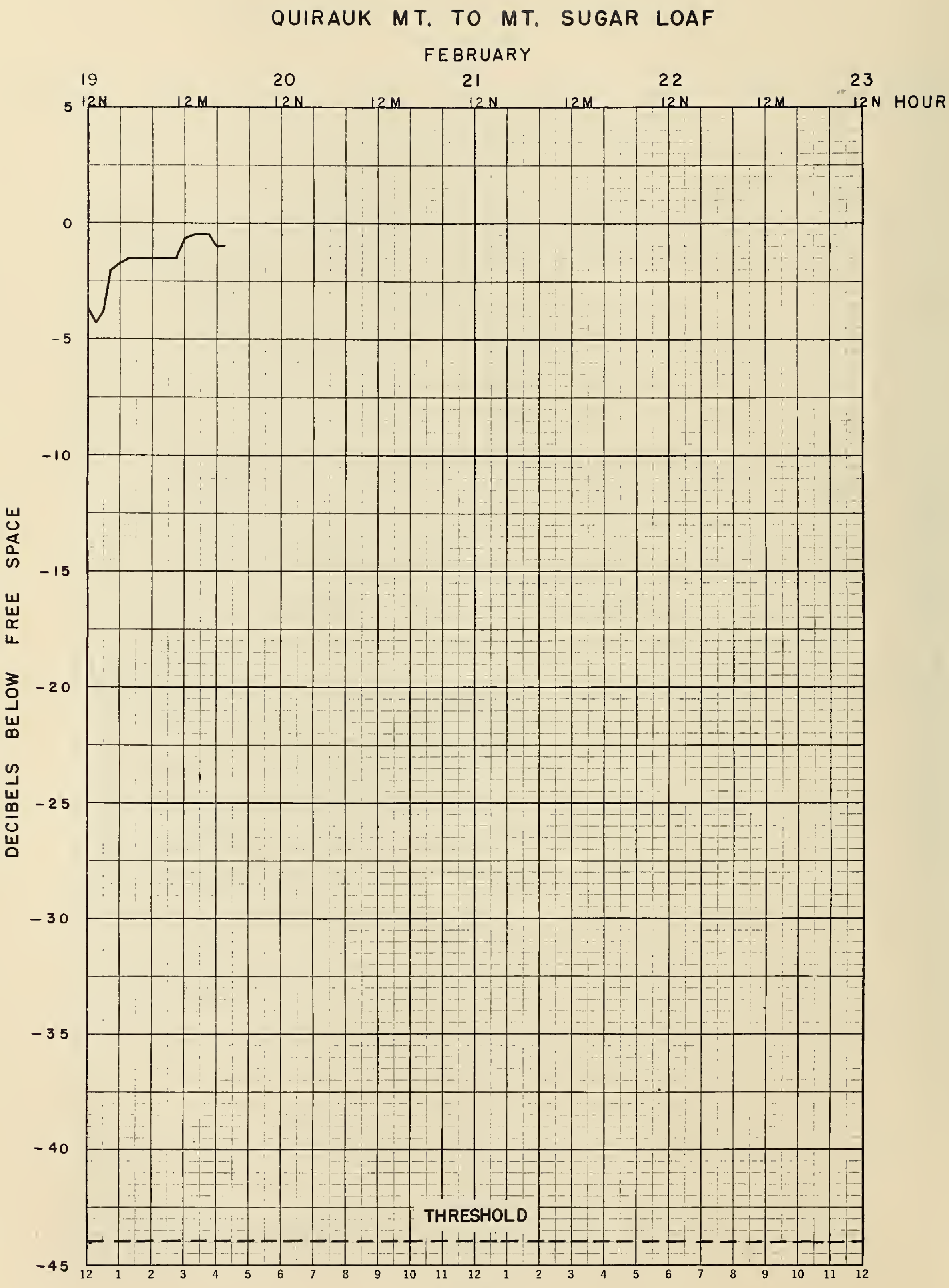

QUIRAUK MT. TO MT. SUGAR LOAF
FEBRUARY
19
20
21
22
23
12N
12M
12N
12M
12N
12M
12N
12M
12N HOUR
5
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
DECIBELS BELOW FREE SPACE
THRESHOLD
12 1 2 3 4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12

FIG.5d.

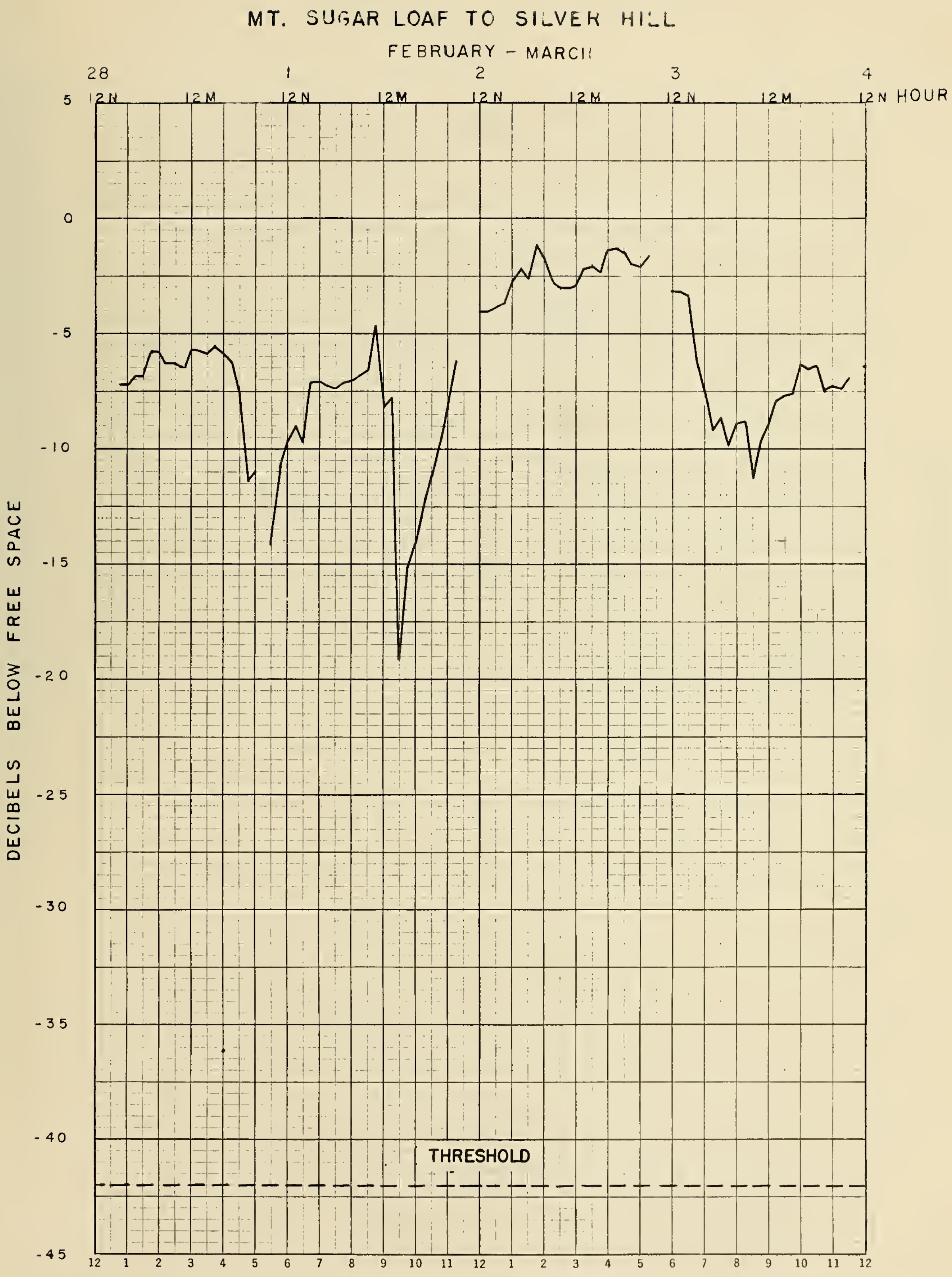

MT. SUGAR LOAF TO SILVER HILL
FEBRUARY - MARCH
28
1
2
3
4
12N
12M
HOUR
DECIBELS BELOW FREE SPACE
5
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
THRESHOLD
12 1 2 3 4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12

FIG.6a.

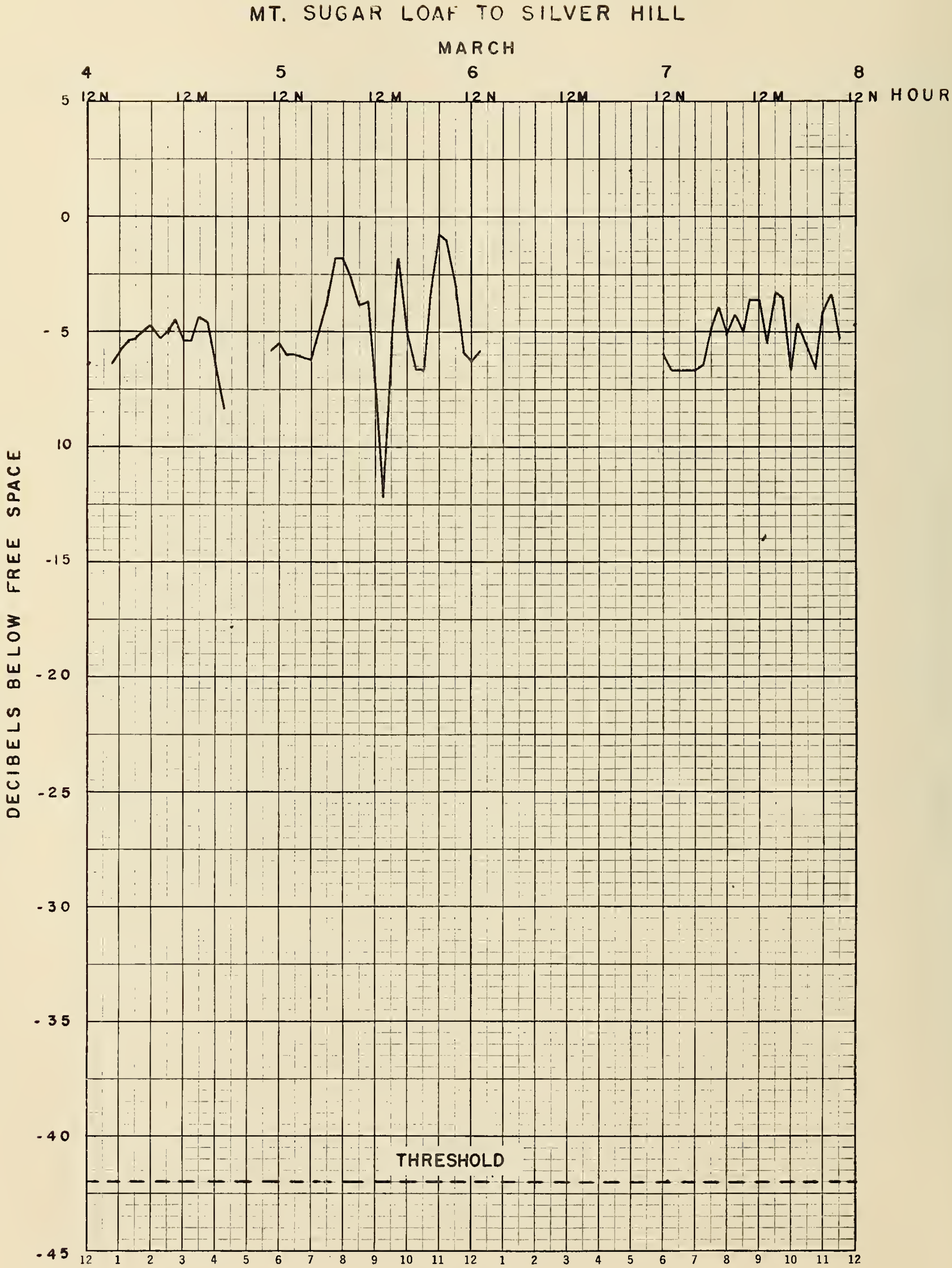

MT. SUGAR LOAF TO SILVER HILL
MARCH
4
5
6
7
8
12 N
12 M
HOUR
DECIBELS BELOW FREE SPACE
5
0
- 5
10
-15
-20
-25
-30
-35
-40
-45
THRESHOLD
12
1
2
3
4
5
6
7
8
9
10
11

FIG.6b.

MT. SUGAR LOAF TO SILVER HILL

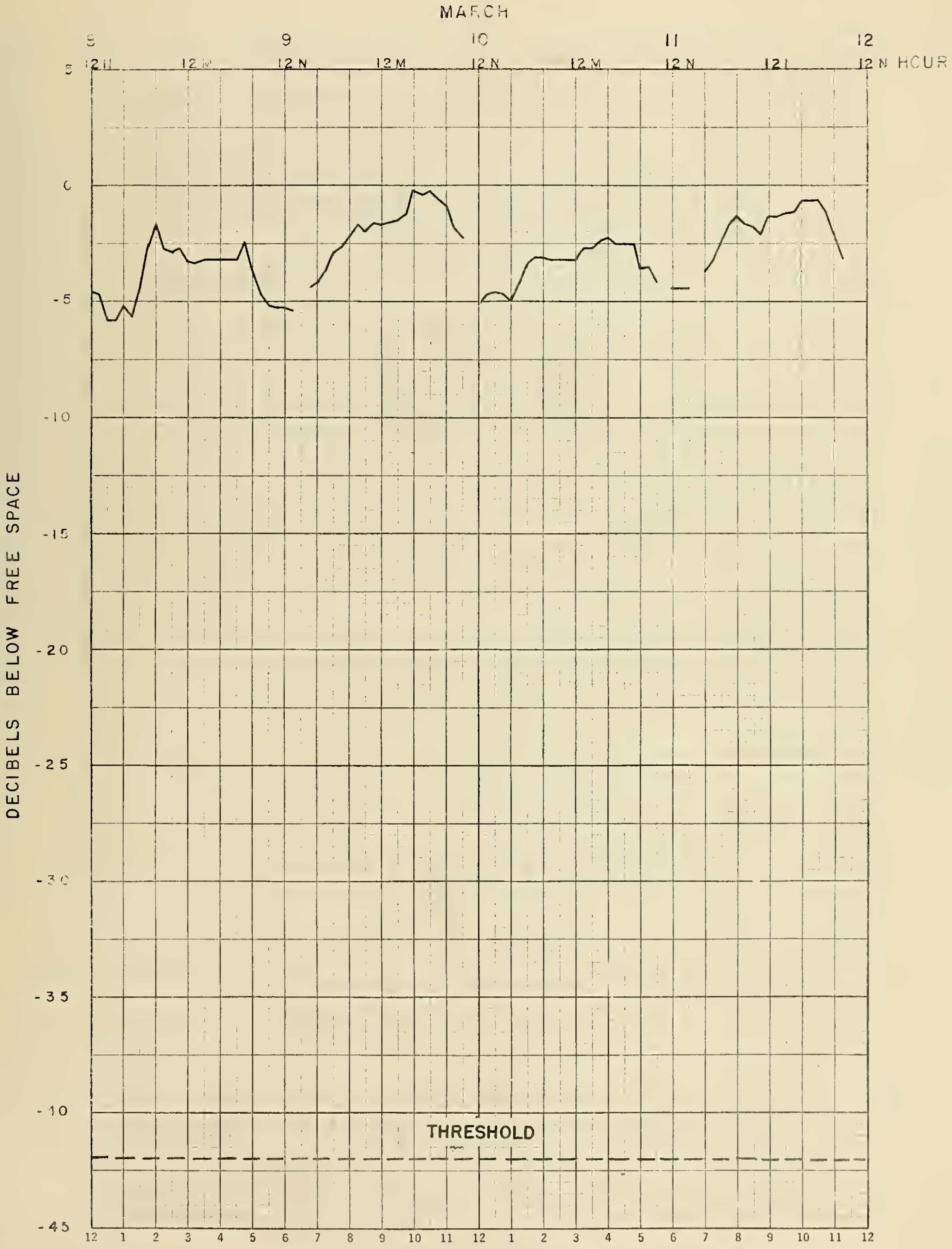
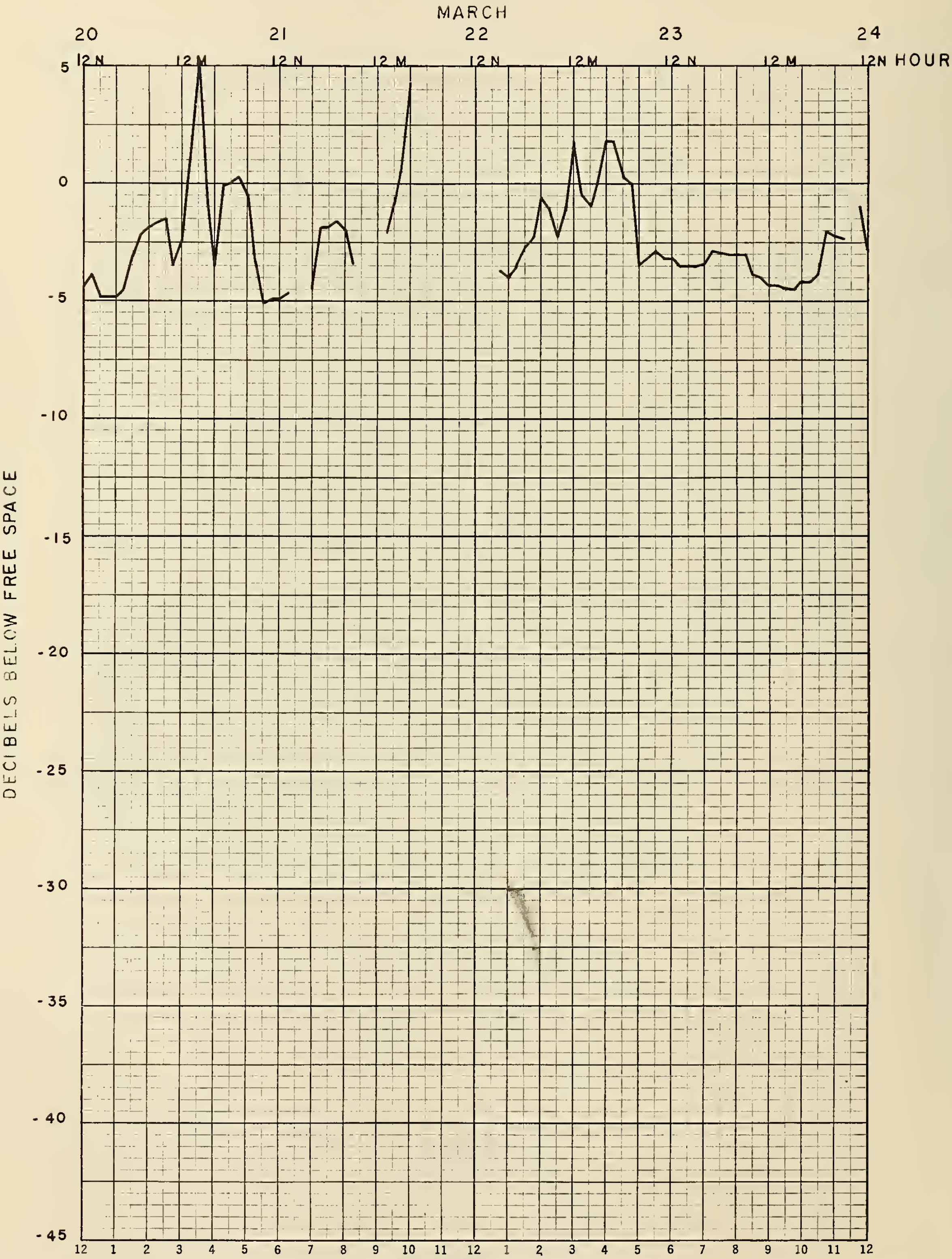


FIG. 6c.

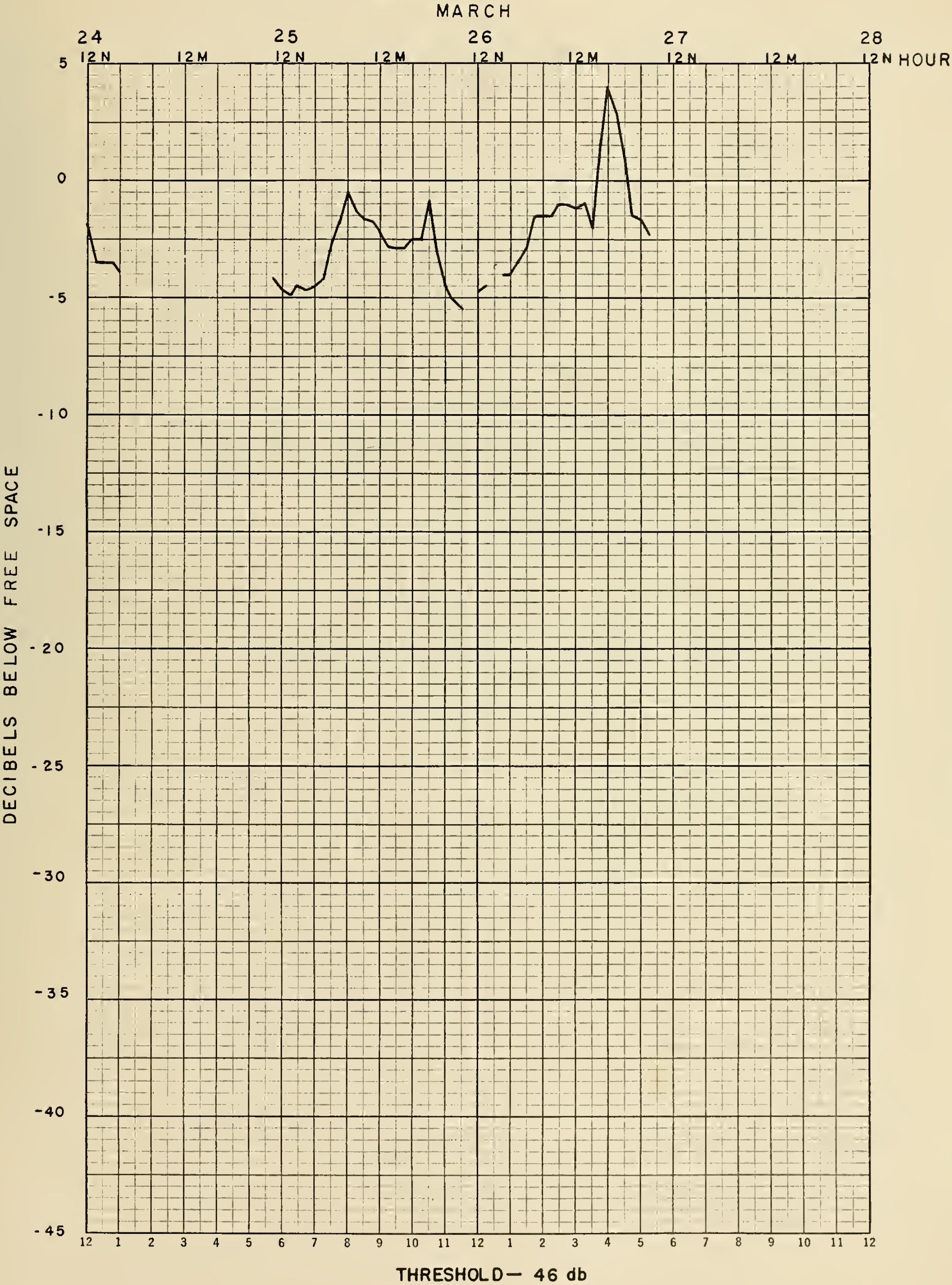
FORT MEADE TO SILVER HILL



THRESHOLD— 46 db

FIG.7a.

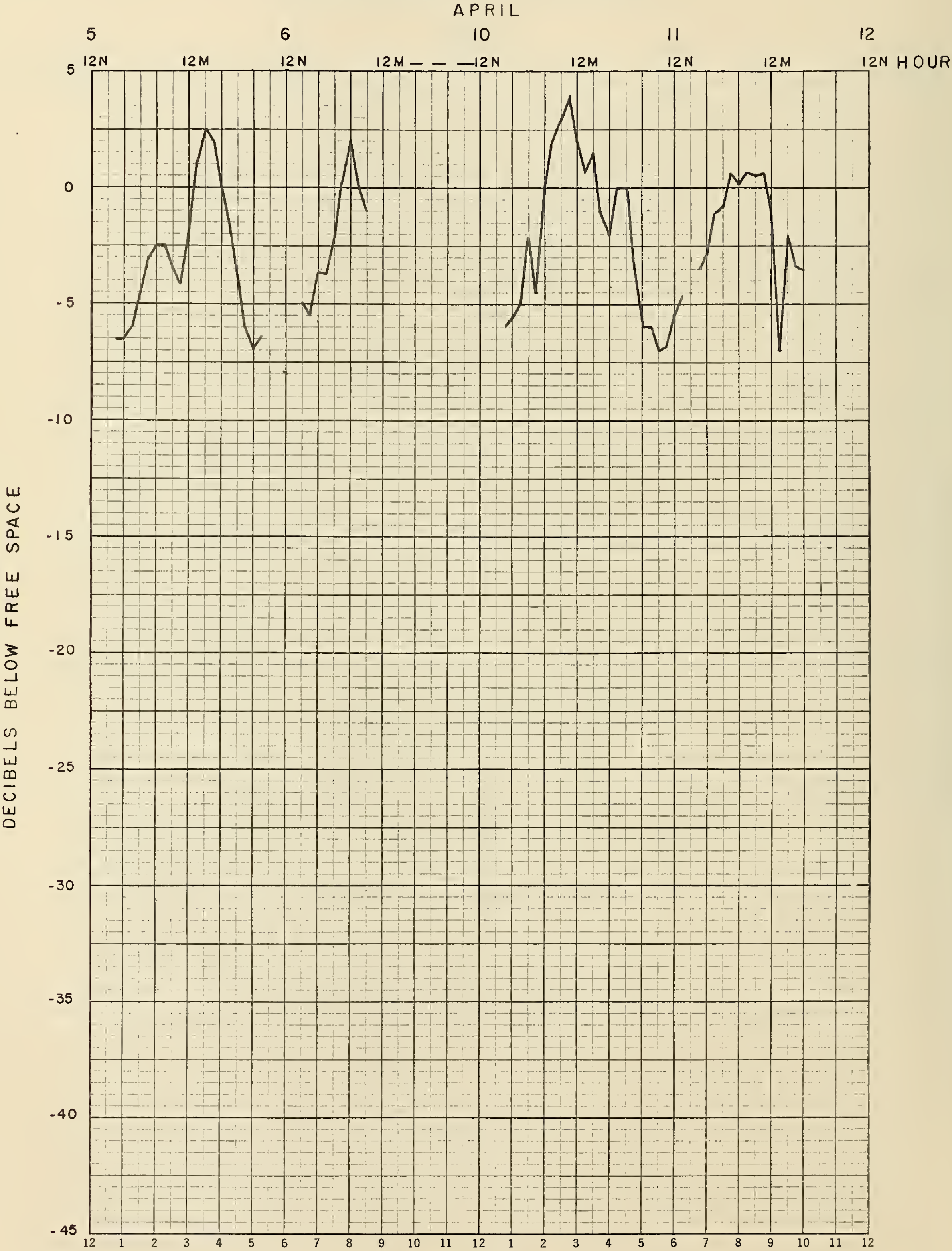
FORT MEADE TO SILVER HILL



THRESHOLD— 46 db

FIG.7b.

SILVER HILL TO LA PLATA



THRESHOLD — 48 db

FIG.8.

Supplement III

418 Mc PROPAGATION MEASUREMENTS OVER THE CEDAR RAPIDS - QUINCY PATH

By

M. T. Decker and H. B. Janes

Supplement III

418 MC PROPAGATION MEASUREMENTS OVER THE CEDAR RAPIDS-QUINCY PATH

By

M. T. Decker and H. B. Janes
National Bureau of Standards
Colorado Springs, Colorado

ABSTRACT

The transmitting, receiving and recording facilities used in propagation measurements made at 418 Mc during the period May to December, 1951 over the 133.9-mile Cedar Rapids-Quincy path are described. The discussion of the received signal power data includes an analysis of variations in instantaneous signal level, as well as analysis of diurnal and seasonal variations in hourly median signal levels.

INTRODUCTION

A knowledge of the losses involved in the propagation of radio energy is essential to the prediction of the range and reliability of any radio communication system. In order to obtain data on the factors which affect radio propagation in the frequency range from 100 to 1000 Mc, the National Bureau of Standards has been conducting and coordinating an extensive program for the measurement of losses in the transmission of radio energy over representative types of terrain throughout the United States. To provide information on propagation characteristics of the 400 to 500-Mc frequency range at distances far beyond the radio horizon, the Central Radio Propagation Laboratory of the National Bureau of Standards, with the assistance of the Department of Defense, has been making field strength measurements between Cedar Rapids, Iowa and Quincy, Illinois, a distance of 134 miles. A map indicating the transmission path is shown in Fig. 1. In order to obtain reliable information on the variations in signal strength at this distance, it is believed that measurements must be made over a long period of time. For this reason seasonal as well as instantaneous and diurnal variations in signal levels are being studied. The purpose of this report is to present the method by which data were gathered and the results of measurements made during the period April 30 to December 15, 1951. This includes eight recording periods, each of roughly two weeks' duration, during which simultaneous recordings were made of the 418-Mc signal using two low receiving antennas having different gain characteristics.

TRANSMITTING LOCATION

Transmission for this program was provided by the Collins Radio Company of Cedar Rapids, Iowa, under contract with the National Bureau of Standards. Transmitting equipment was located at the Cedar Rapids Municipal Airport.

TRANSMITTER

The resnatron transmitter used is capable of a continuous-wave output on the order of 50 kw in the 400-Mc region. For the Cedar Rapids-Quincy studies an unmodulated signal of approximately 23 kw was fed to a moderately directional antenna beamed toward Quincy. Since system frequency stability is a very important factor in this program, the transmitter is crystal-controlled. Basic units of the transmitter are 1) crystal oscillator, 2) frequency multipliers, 3) intermediate power amplifier, and 4) final resnatron power amplifier.

The final amplifier tube is of particular interest due to its large power handling capabilities at this frequency. The resnatron is a continuously pumped water-cooled tetrode with integral RF circuits[1/]. The tube has high power gain combined with excellent RF shielding characteristics. Physical dimensions include a length of 54 in, a diameter of 18 in, and a weight of 210 lbs. The directly heated cathode requires 800 to 1000 amperes at 2.6 to 2.8 volts AC or DC.

Anode and screen of the tube are connected internally and are operated at ground potentials. RF input power is fed through 3-1/8 in coaxial transmission line, and the output is taken out through a 6 by 22 in wave guide, both at ground potential.

TRANSMITTING ANTENNA

The 6 by 22-in wave guide from the transmitter is terminated in a pyramidal horn mounted on the roof of the hangar containing transmitting equipment. The axis of the horn is approximately 41 feet above local terrain. Measurements made by theCollins Radio Company indicated a gain of 14.5 db relative to an isotropic radiator[2/].

RECEIVING LOCATION

The receiving location is the site of the WTAD-FM transmitter near Quincy, Illinois. The selection of this site was made after a survey of several possible locations by the Collins Radio Company under contract with CRPL. Preliminary measurements made in March, 1950 showed that reception and recording of a 400-Mc signal from Cedar Rapids was feasible. Advantages of the WTAD-FM location included a 750-foot grounded tower and the availability of space for recording equipment in the transmitting building at the base of the tower. Recording at this site was carried on by the Collins Radio Company through 1950 and results of this previous work have already been reported[3/]. In March, 1951 the operation of the receiving site was begun by CRPL, while the operation of the transmitter in Cedar Rapids was continued by the Collins Radio Company. Recordings were made during 1951 using antennas at low elevations, while during 1952 and 1953 data are being obtained from antennas mounted on the tower at various elevations from 30 to 665 feet. The latter measurements will be covered in future reports.

A block diagram of receiving equipment is shown in Fig. 2. Description of the individual components follows.

RECEIVING ANTENNAS

One of the receiving antennas consists of a half-wave dipole in a corner reflector and the other a half-wave dipole mounted in a 10-foot parabolic reflector. They are mounted side by side with a horizontal separation of about 40 feet. Although they are situated in the same horizontal plane, the ground has a considerable slope so that the dipole in the corner reflector is 5.5 feet above the immediate ground level and the dipole in the parabola is 8.5 feet above ground. Both are matched to 50-ohm transmission line, and fed to receivers with RG8/U coaxial cable. The gains relative to an isotropic radiator are 21.5 db for the parabola and about 10 db for the corner reflector. Measurements were made by the Collins Radio Company[4/].

RECEIVERS

The 400 to 420-Mc field strength meters used for these measurements were built to CRPL specifications by the Polarad Electronics Corporation of Brooklyn, N. Y. They are of the single superheterodyne type employing a variable local oscillator and an intermediate frequency of 36 Mc. A block diagram of the receiver is shown in Fig. 3.

The incoming signal is fed into a coaxial type cavity preselector which serves to reduce response to spurious and image frequencies. A pencil triode in a coaxial type mounting is then used as an RF amplifier. Crystal mixing is employed to convert to the intermediate frequency of 36 Mc. The injection voltage is obtained from a 6F4 oscillator which may be tuned from 364 to 386 Mc to give the receiver its range of 400 to 420 Mc. Coaxial cavity tuning is also used in the oscillator as this method provides convenient circuit components at these frequencies. Amplification of the intermediate frequency is accomplished with four stages of pentode amplifiers. The band-pass characteristic provides for constant gain to within 1 db for a carrier frequency variation of 150 kc from the center of the band. The AVC characteristic gives a receiver output which is approximately linear with logarithmic signal input.

A detector following the last stage of amplification of 36 Mc supplies three separate output circuits of the receiver. The first of these is an audio amplifier which may be used for aural monitoring of any incoming signal. The second is a dc amplifier used to operate a 0 to 5-milliampere recording meter. The output of this circuit is designed to provide critical damping for a type AW Esterline-Angus recorder. A meter integral with the receiver allows monitoring of this output with or without the external recorder. This recorder provides a continuous plot of signal strength versus time. Examples of this recording are shown in Figs. 4 and 5. A third dc amplifier whose output range is from 0 to -10 volts is used for the operation of the time totalizing recorder.

TIME TOTALIZING RECORDER

The time totalizing recorder driven from the 0 to -10 volt output consists of 10 channels, each of which includes a dc amplifier, and a bistable multivibrator that actuates a fast acting relay. The relay in turn operates a motor which drives a revolution counter. The multivibrator may be adjusted to operate the relay at various levels of input voltage from the dc amplifier. Thus, the revolution counter will indicate the total time that the signal exceeds a preset level. Hourly readings of the counters were made with an automaticallyactuated 35-mm camera. This equipment is of an advanced design but similar to that described previously in connection with this recording program[5].

CALIBRATION

The magnitude of the incoming signal power at the antenna terminals was determined by the substitution for the antenna of a calibrated signal generator of impedance equal to the antenna transmission line impedance and with comparable output voltage. With the relatively broad band pass of the receivers, commercially available generators proved to be satisfactory for the purpose. During the first portion of the measurement period (May to September), both receivers were calibrated with a Measurements Corporation Model 84 generator, and for the remainder of the year, a General Radio Model 1021 generator was used. The output calibrations of both generators were checked against a third signal generator which had been calibrated by the High Frequency Standards Section of CRPL. The corresponding data were corrected to allow for the difference from the calibrated standard.

RECORDING SCHEDULE

The schedule of field strength recording covered in this report is given in Table I. Also shown is the total number of hours of useful data obtained during each period.

CHARACTERISTICS OF THE TRANSMISSION PATH

In Fig. 6 a profile for each end of the transmission path has been plotted. These profiles are based on a radius of four-thirds the actual earth's radius in order to allow for standard atmospheric refraction. Unfortunately, there are no topographic maps available for the middle portion of the path. It will be noted that the radio horizon is located approximately 11 miles from the transmitting antenna at Cedar Rapids, while the distance from the receiving antennas to their common radio horizon is only approximately three-quarters of a mile. Assuming standard atmospheric refraction, the receiving antennas were located approximately 7100 feet below the radio horizon of the transmitting horn.

EXPLANATION OF UNITS

Although the signal power recording equipment was calibrated in terms of available power from the receiving antenna[6], the data presented in this report are expressed in terms of the ratio (in decibels) of the power received at the receiving antenna terminals to that which would be received in free space.

The conversion of available power at the antenna terminals to the received power relative to that available in free space is given by:

$$\text{received power in db below free space} = 10 \log_{10} \frac{P_t \left(\frac{\lambda}{4\pi d}\right) G_t G_r}{P_a}$$

where P_t is the power input to the transmitting antenna

d is the distance between transmitting and receiving antennas expressed in the same units as λ.

G_t is the free space gain of the transmitting antenna relative to an isotropic antenna

G_r is the free space gain of the receiving antenna relative to an isotropic antenna

P_a is the measured available power from the receiving antenna.

For a frequency of 418 Mc and a distance of 133.95 miles, this equation reduces to:

received power in db below free space =

$$10 \log_{10} P_t - 10 \log_{10} P_a + 10 \log_{10} G_t + 10 \log_{10} G_r - 131.54$$

As was previously mentioned, G_t was 14.5 db while G_r was 21.5 db for the parabola and 10 db for the corner reflector. P_t was determined for each hour by averaging the three transmitter output readings for that hour contained in the transmitter log. This procedure was considered advisable since there was sometimes considerable variation in transmitter output from hour to hour.

GENERAL APPEARANCE OF THE SIGNAL

Figs. 4 and 5 show representative samples of received power recordings made in Esterline-Angus graphic ammeter charts. A chart speed of 3 in. per hour was used for all recordings. That there was a marked difference between the daytime and nighttime signals recorded during the summer months is clearly shown in Fig. 4. Although the short-term fading range appears to be quite similar for the day and night signals, there is a considerable increase in median signal magnitude during the night. In general, the strong nighttime signal was accompanied by a decrease in the short-term fading rate. This was not always true of the early winter signal. During November and December there was often no clear-cut rise in signal strength during the night. On the other hand, a relatively high signal during the daylight hours, such as appears in Fig. 5 was not at all uncommon. These effects will be more clearly illustrated by the diurnal variation analysis which is included later in this report. It will be noticed that the fading recorded by the two antennas separated normal to the path by approximately 17 wave-lengths appears to be almost perfectly correlated, at least so far as can be discerned at this chart speed.

DISTRIBUTION OF SIGNAL LEVEL WITH TIME

Because of the characteristically rapid and violent fading which is evident in these samples, it would have been difficult, if not impossible, to obtain an accurate quantitative description of the signal by analysis of the charts alone. For that reason time-totalizing recorders were used and totalizer counter readings made each hour by the automatic photographic equipment mentioned previously. By taking the differences between successive hourly readings for each of the 10 channel counters, a distribution of instantaneous signal levels is obtained for each hour. These hourly distributions form the basis for all received power data presented in this report. The Esterline-Angus charts are, of course, indispensable for displaying the fading rate and general appearance of the signal, and for detecting equipment failures which might not be discovered by analysis of the totalizer data alone.

The information obtained from the hourly distributions has been summarized in two ways. The first consists of a distribution of instantaneous levels recorded during two 3-hour periods of the day (3 to 6 AM, Noon to 3 PM) for each transmission period. These were obtained by determining the percent of time each of ten signal levels (corresponding to the 10 totalizer channel settings) was exceeded for all hours within a given 3-hour period during an entire transmission period.

In addition, a distribution of hourly median signal levels was made for each 3-hour period of the day for each recording period. Examples of these two types of distribution (i.e. instantaneous and hourly median signal level) are shown in Figs. 7 to 14 for the parabolic receiving antenna and Figs. 15 to 22 for the corner reflector receiving antenna. The hours of 3 AM to 6 AM and Noon to 3 PM were chosen, since, in general, the over-all median signal level was at its maximum and minimum, respectively, during these hours; and they may therefore be considered as representing the extremes in propagation conditions.

In Figs. 23 and 24 distributions of instantaneous levels for the entire period from May to December are plotted for the same two periods of the day. From these curves and from the curves in Figs. 7 to 22, it will be seen that the slope of the 3 AM to 6 AM distribution is in general steeper than that of the Noon to 3 PM distribution, indicating a wider range of variation in signal during the early morning hours. An analysis of this type does not, of course, distinguish between short-term and long-term variations. A study of short-term fluctuations in signal level about the hourly median level is being undertaken and will be the subject of a subsequent report. Preliminary work indicates, however, that the short-term fading for 418 Mc is essentially Rayleigh distributed regardless of time of day or season of the year over this transmission path.

Distributions of all hourly medians recorded during each transmission period are shown for both the parabolic and corner reflector antennas in Figs. 25 to 32. Fig. 33 shows the distributions of all hourly medians recorded with the two antennas during all periods from May to December.

DIURNAL VARIATION OF MEDIAN SIGNAL LEVELS

Figs. 34 to 37 show the variation of signal levels exceeded by 10 per cent, 50 per cent and 90 per cent of the hourly medians versus time of day for each recording period. These curves were prepared from the distributions of hourly medians by 3-hour periods which were discussed previously.

It will be noted that the magnitude of the diurnal variation shows a marked decrease during the early winter months, the characteristic shape of the curves obtained during the summer being almost unrecognizable during November and December. The lack of a clear-cut diurnal pattern during the early winter is strikingly illustrated in the samples of chart recordings shown in Figs. 4 and 5. It will be seen that on November 29 the signal during the day reached much higher median values than at any time the following night. As pointed out previously, to apply the word "typical" to this sample may be somewhat misleading since examination of the data for November and December reveals that a high signal such as that recorded from 10 AM to Noon on the 29th might occur at any time of the day or night, and indeed, often did not occur at all for a period of several days.

In addition to the variation in the median value of the hourly medians with time of day, there is also a diurnal variation in the variability or dispersion of the individual hourly levels. This can be seen in Figs. 34 to 37 by noting the difference between the levels exceeded by 10 per cent and 90 per cent of the hourly medians at various hours of the day. To illustrate this effect more clearly Fig. 38 shows a plot of this difference between 10 per cent and 90 per cent levels (sometimes referred to as interdecile range) for each receiving antenna and recording period. It should be noted that the periods of greatest variability coincide, in general, with the periods of strongest median fields. This can also be seen in the chart samples in Figs. 4 and 5. During the night and early morning hours when the median level is relatively strong, the signal is still subject to deep fades which often reach the noise level of the receiver.

In Figs. 39 and 40 the median level of all the hourly medians recorded during the hours of 3 AM to 6 AM and Noon to 3 PM is plotted versus time of year. The points are joined by a dotted line. For purposes of comparison, a plot (shown by the solid line) was also made using the median levels obtained from the distributions of instantaneous levels in Figs. 7 to 22. These curves serve to illustrate the fact that the month-to-month variation in the weak early afternoon signal is very similar to the variation in the strong early morning signal. It will be noticed, however, that along with the increase in median signal level during the summer months, there is also an increase in the difference between the early morning and early afternoon signals. This effect is, of course, also evident in the diurnal variation curves in Figs. 34 to 37. Figs. 41 and 42 show curves representing the levels exceeded by 10 per cent, 50 per cent and 90 per cent of all hourly medians recorded during each measurement period. Superimposed on these curves is a plot of the average earth's radius factor k for each month[5/]. The values of k were determined by B. R. Bean of NBS from meteorological measurements made at Joliet, Illinois, and Omaha, Nebraska. These curves indicate a fairly close correlation between median signal level and k.

COMPARISON OF MEASURED SIGNAL LEVELS WITH COMPUTED DIFFRACTION FIELD

It is interesting to compare the measured median signal levels with the computed values of ground wave field intensity obtained by assuming diffraction over a finitely-conducting spherical earth. Using the method developed by Norton[6/], the power received from the diffraction field is computed as 156.91 db below free space for the parabola, and 160.62 db below free space for the corner reflector. In these calculations, the actual heights of the transmitting and receiving antennas above local terrain were used for h_1 and h_2, respectively. Also, a value of 1.405 was used for k, or the effective earth's radius factor. This k was obtained by averaging the monthly k values shown plotted in Fig. 41. From the over-all median signal levels shown in Figs. 41 and 42, it will be seen that the measured power levels are from 82 to 114 db higher than the computed levels for the parabola and 92 to 124 db higher for the corner reflector. It is evident from this that the ground wave component constituted only a small part of the total received field. The major portion was apparently received from the troposphere as a result of scattering[7] or some other propagation mechanism.

COMMENTS ON RELATIVE RECEIVING ANTENNA GAINS

As stated previously, the measured free space power gain of the parabola was 21.5 db, and of the corner reflector, 10 db. However, if the received power data from the two antennas are expressed in terms of decibels relative to some common reference level (e.g., the power output of the transmitter), it is obvious that the expected 11.5 db difference in power levels is by no means realized. The average ratio of power received by the parabola to the power received by the corner reflector for the entire period from May to December is 6.1 db. Furthermore, there is pcssibly a seasonal variation in this effective relative gain. Fig. 43 shows a plot of the average difference in power levels received by the two antennas for each recording period. These differences were obtained by averaging the ratios of hourly median power levels for all hours during which both recording systems were in operation.

The fact that the free space gain of the parabola relative to the corner reflector was not realized may plausibly be explained on the basis of tropospheric scattering. If we assume that the major portion of the received field was contributed by scattering from atmospheric discontinuities, it follows that this scattered signal could be expected to arrive at the receiving antenna from a number of directions, depending upon the distribution of the scattering elements in space. Since the major lobe of the parabola pattern is sharper than that of the corner reflector, the effective gain of the parabola suffers more from the scattering process than does the gain of the less directional corner reflector. Assuming the correctness of the above explanation, the seasonal variation of the relative effective gain of the two antennas implies a very large variation in the height distribution of the scattering elements with time of year.

ACKNOWLEDGEMENTS

The data presented in this report were processed and analyzed by the Data Analysis Group of the Cheyenne Mountain Field Station in Colorado Springs, Colorado. The authors wish to thank J. W. Herbstreit and K. A. Norton for their very valuable advice and assistance in the preparation of the report.

TABLE I

RECORDING SCHEDULE

418 Mc Field Strength Measurements Between
Cedar Rapids, Iowa, and Quincy, Illinois, during 1951

Transmitting Period*	Recording Period		Number of Hours	
	Parabola	Corner Reflector	Parabola	Corner Reflector
Apr 30-May 12	Apr 30-May 11	May 2-May 11	329	285
May 22-May 27	May 22-May 27	May 22-May 27		
Jun 11-Jun 14	Jun 11-Jun 14	Jun 11-Jun 12	252	228
Jun 21-Jun 30	Jun 21-Jun 30	Jun 21-Jun 30		
Jul 24 - Aug 4	Jul 24-Aug 4	Jul 24-Aug 4	231	229
Aug 13-Aug 25	Aug 13-Aug 25	Aug 13-Aug 25	257	230
Sep 10-Sep 23	Sep 10- Sep 23	Sep 11-Sep 23	225	202
Oct 1-Oct 13	Oct 1-Oct 13	Oct 1-Oct 13	249	238
Oct 28-Nov 10	Oct 28-Nov 10	Oct 28-Nov 10	279	266
Nov 26-Dec 15	Nov 26-Dec 3	Nov 26-Dec 10	249	297
	Dec 10-Dec 15			

*The transmitter was also operated during March 20-24 (0800-1700 only) and April 2-13 (0500-2100 only). However, due largely to initial recording equipment failures and adjustments, very few reliable data were obtained during these periods.

REFERENCES

1/ "Very High-Frequency Techniques," Radio Research Laboratory Harvard University, Vol. I, pp. 445-472, McGraw-Hill Book Co. New York, 1947.

2/ I. H. Gerks, "Propagation at 412 Mc From a High-Power Transmitter," Proc. IRE, Vol. 39, No. 11, pp. 1374-1382, November, 1951.

3/ R. P. Decker, "Notes on the Analysis of Radio Propagation Data," Proc. IRE, Vol. 39, No. 11, pp. 1382-1388, November, 1951.

4/ K. A. Norton, "Transmission Loss in Radio Propagation," Proc. IRE, Vol. 41, No. 1, pp. 146-152, January, 1953.

5/ B. R. Bean, "The Geographical and Height Distribution of the Gradient of Refractive Index," Proc. IRE, Vol. 41, No. 4, pp. 549-550, April, 1953.

6/ K. A. Norton, "Calculation of Ground Wave Field Intensity Over a Finitely Conducting Spherical Earth," Proc. IRE, Vol. 29, No. 12, pp. 623-639, December, 1941.

7/ J. W. Herbstreit, K. A. Norton, P. L. Rice, and G. E. Schafer, "Radio Wave Scattering in Tropospheric Propagation," 1953 Convention Record of the Institute of Radio Engineers.

CEDAR RAPIDS TO QUINCY TRANSMISSION PATH

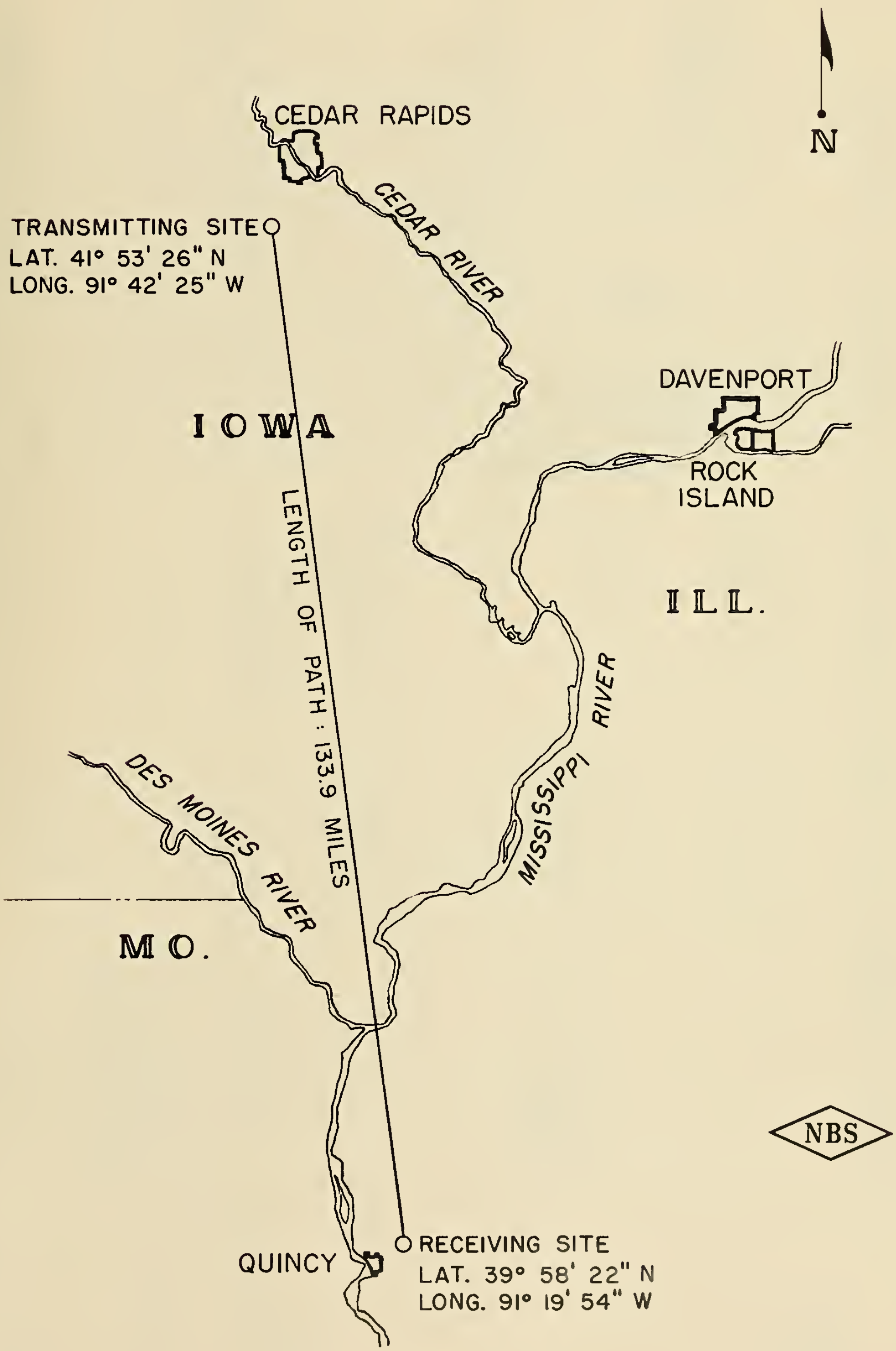
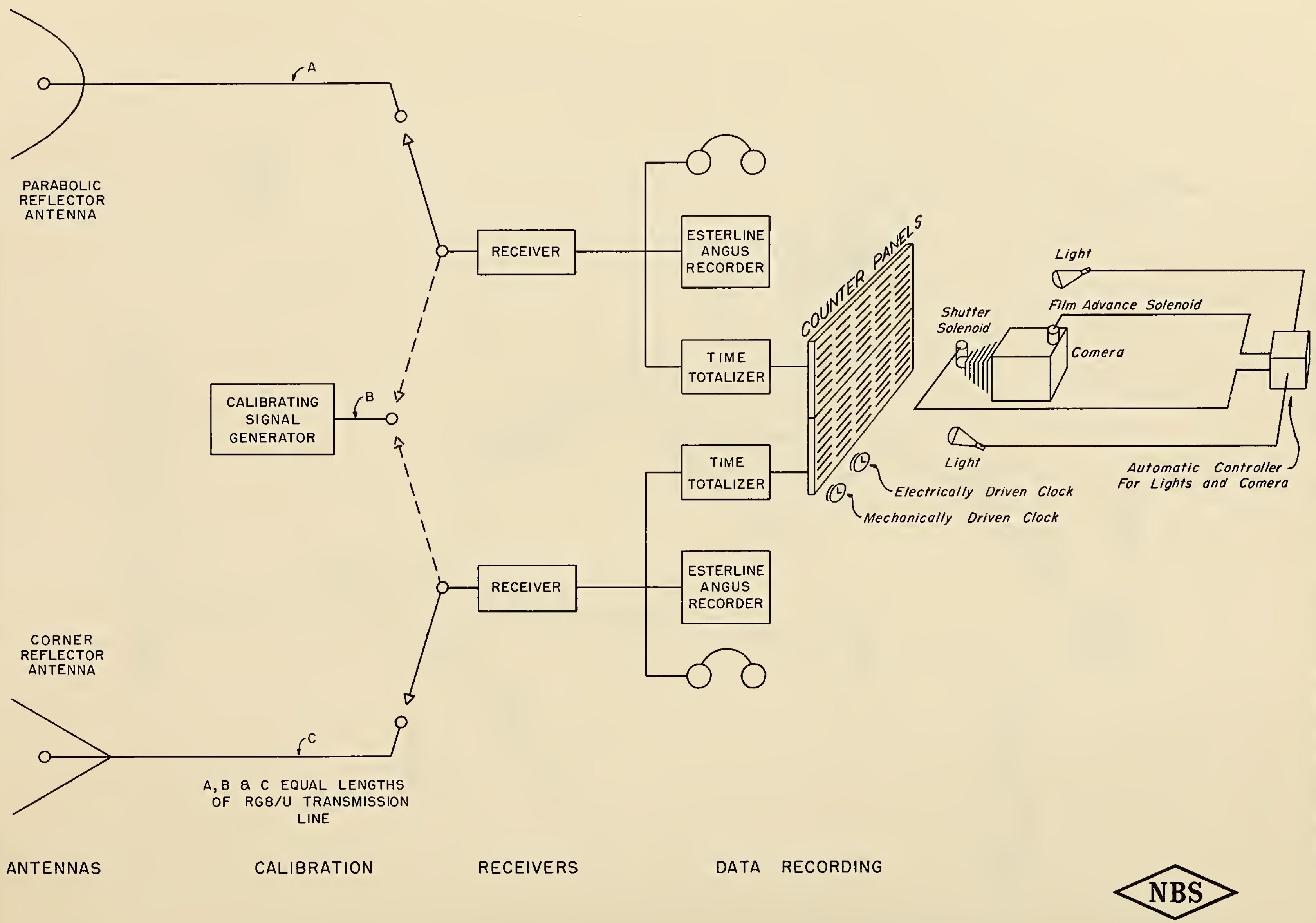
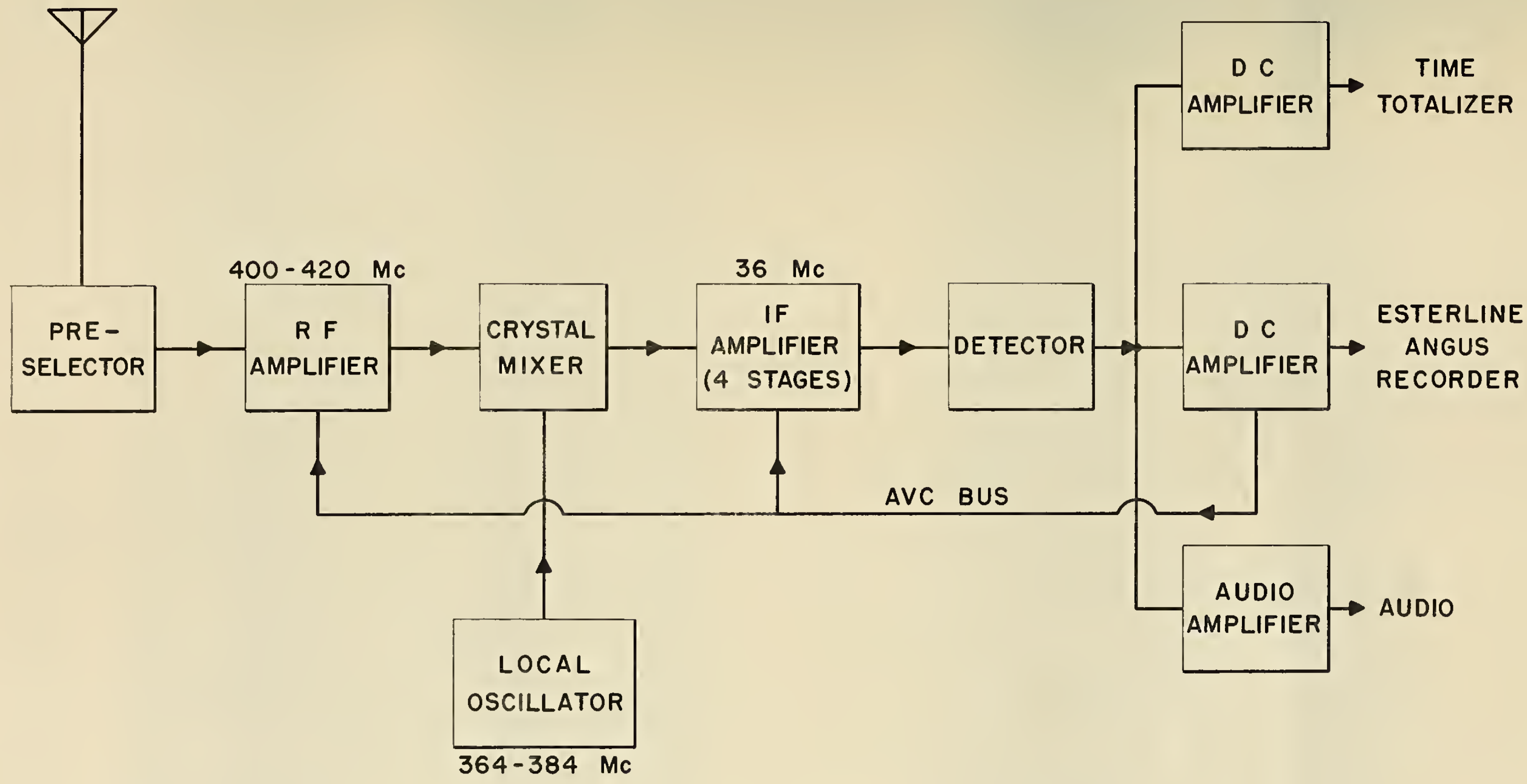


FIG I



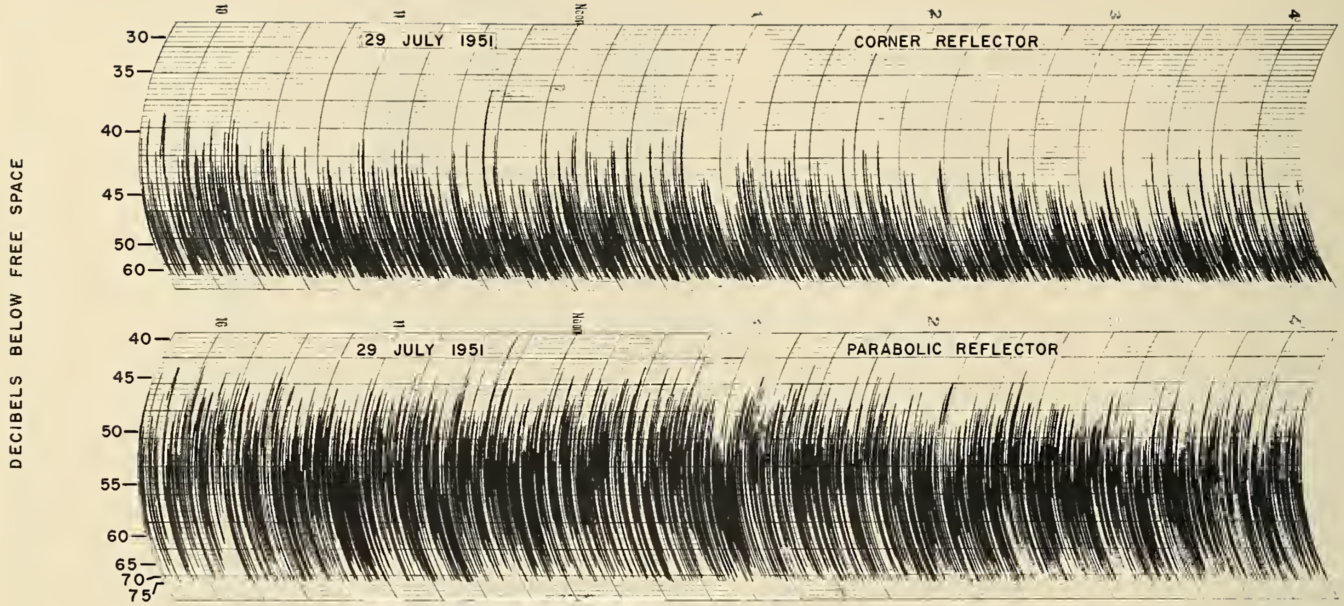
RECEIVING EQUIPMENT AT QUINCY, ILLINOIS

FIG 2

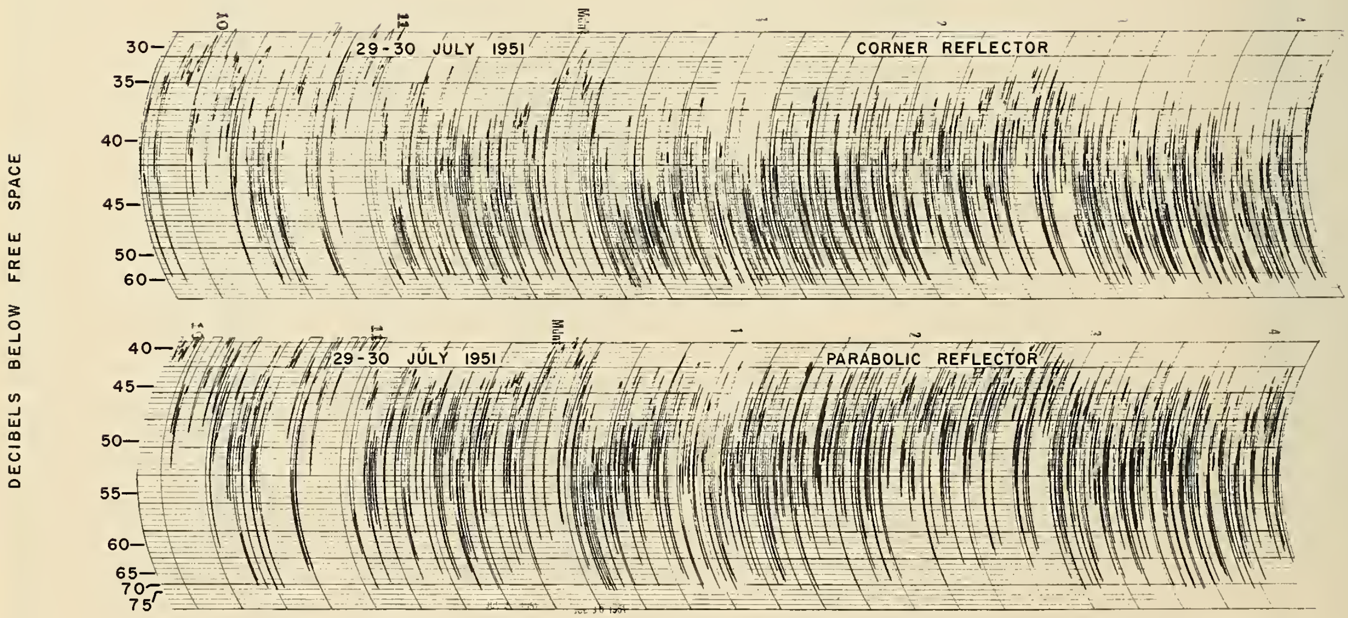


BLOCK DIAGRAM OF 400-420Mc FIELD STRENGTH METER

FIG 3

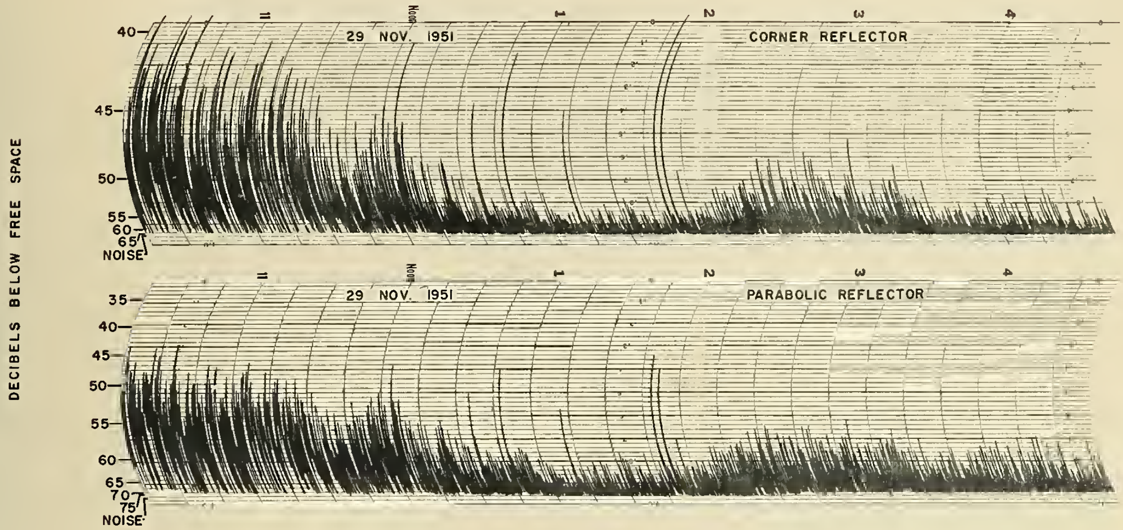


TYPICAL SUMMER SIGNAL — DAY

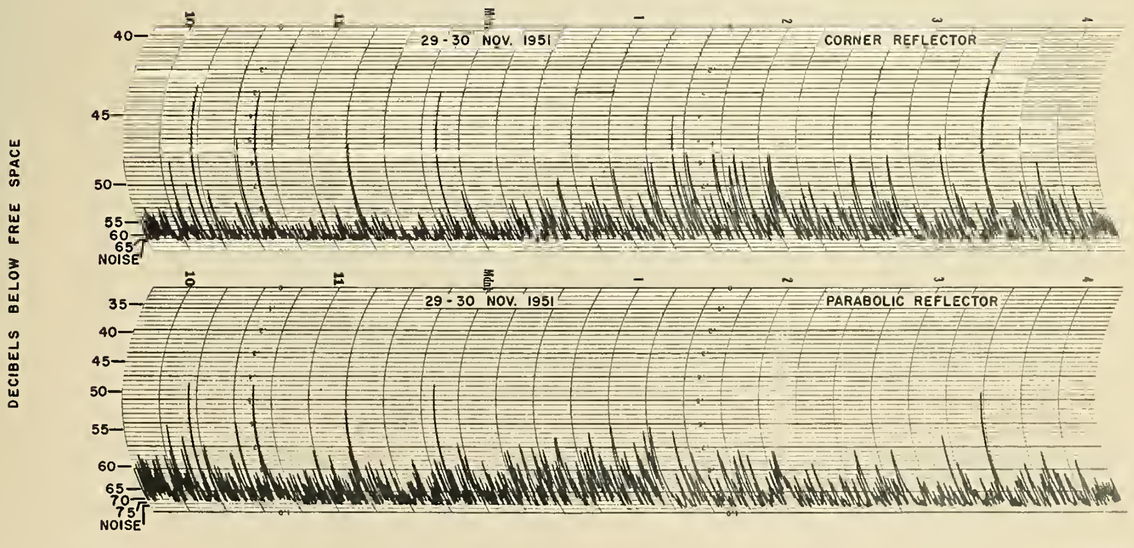


TYPICAL SUMMER SIGNAL — NIGHT

FIG 4



TYPICAL EARLY WINTER SIGNAL – DAY

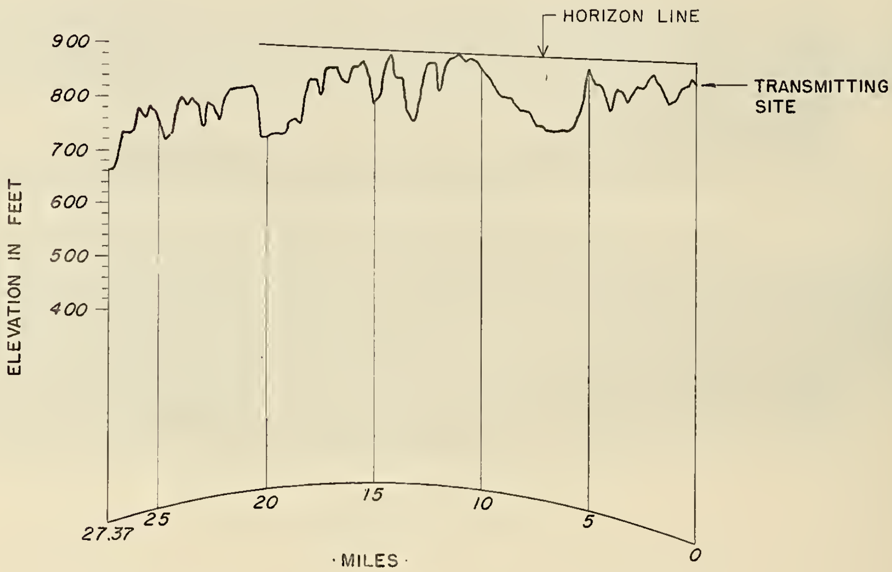


TYPICAL EARLY WINTER SIGNAL – NIGHT

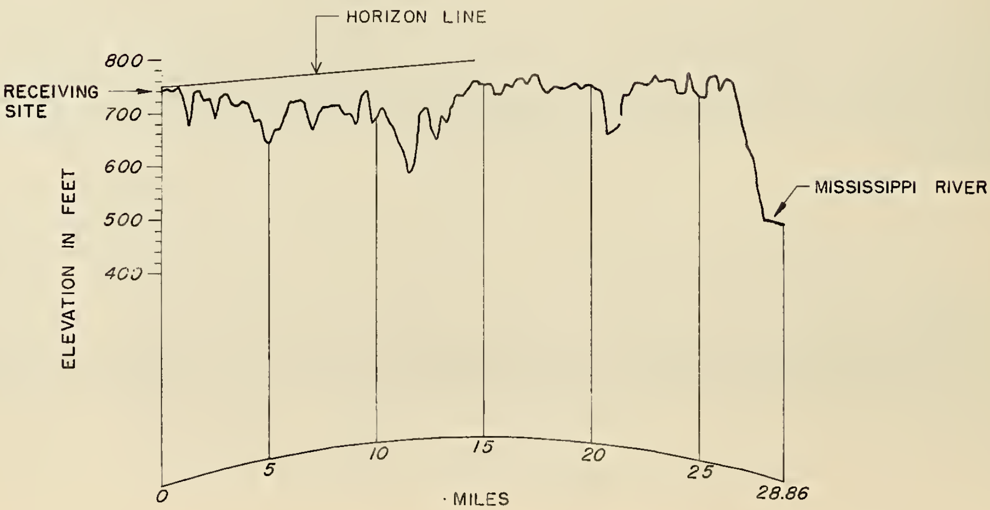
FIG 5

TERRAIN PROFILES OF CEDAR RAPIDS-QUINCY TRANSMISSION PATH

(BASED ON 4/3 EARTH'S RADIUS TO ALLOW FOR STANDARD ATMOSPHERIC REFRACTION)



PROFILE OF TERRAIN IN VICINITY OF TRANSMITTING SITE



PROFILE OF TERRAIN IN VICINITY OF RECEIVING SITE

NBS

FIG 6

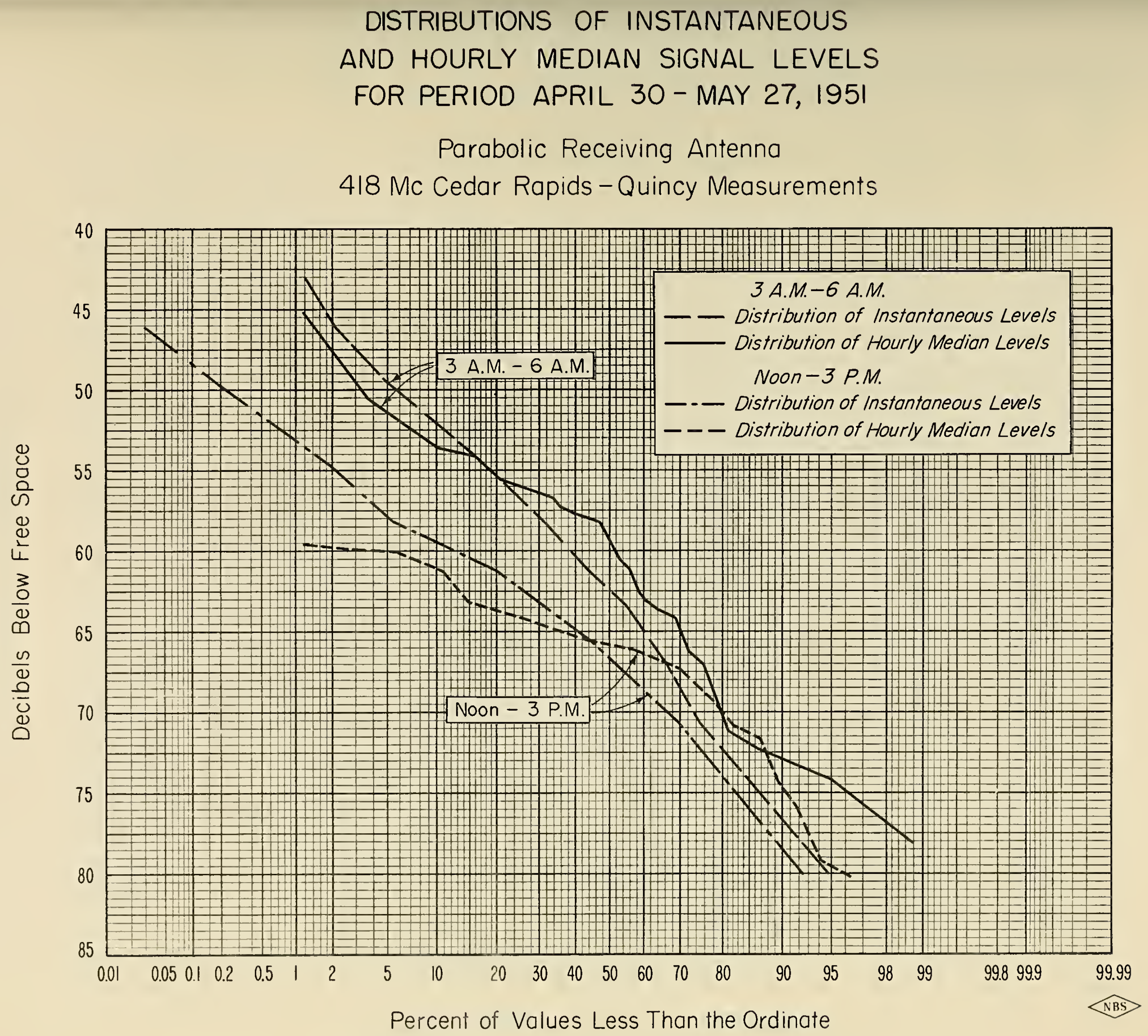

DISTRIBUTIONS OF INSTANTANEOUS
AND HOURLY MEDIAN SIGNAL LEVELS
FOR PERIOD APRIL 30 - MAY 27, 1951
Parabolic Receiving Antenna
418 Mc Cedar Rapids - Quincy Measurements
3 A.M.-6 A.M.
Distribution of Instantaneous Levels
Distribution of Hourly Median Levels
Noon-3 P.M.
Distribution of Instantaneous Levels
Distribution of Hourly Median Levels
3 A.M. - 6 A.M.
Noon - 3 P.M.
Decibels Below Free Space
40
45
50
55
60
65
70
75
80
85
0.01 0.05 0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.8 99.9 99.99
Percent of Values Less Than the Ordinate
NBS

Figure 7

DISTRIBUTIONS OF INSTANTANEOUS
AND HOURLY MEDIAN SIGNAL LEVELS
FOR PERIOD JUNE 11 - 30, 1951

Parabolic Receiving Antenna

418 Mc Cedar Rapids - Quincy Measurements

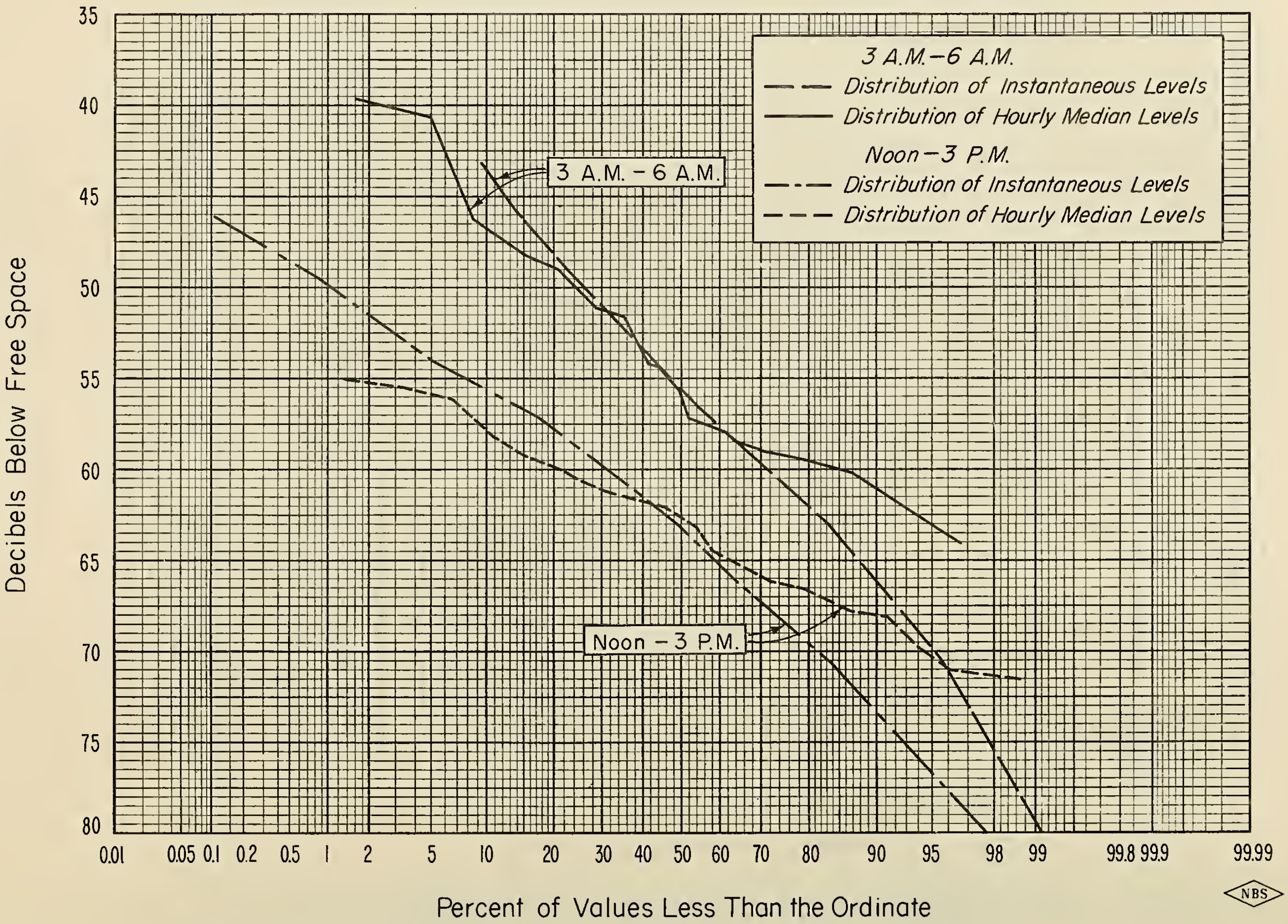


Figure 8

DISTRIBUTIONS OF INSTANTANEOUS AND HOURLY MEDIAN SIGNAL LEVELS FOR PERIOD JULY 24 - AUGUST 4, 1951

Parabolic Receiving Antenna

418 Mc Cedar Rapids - Quincy Measurements

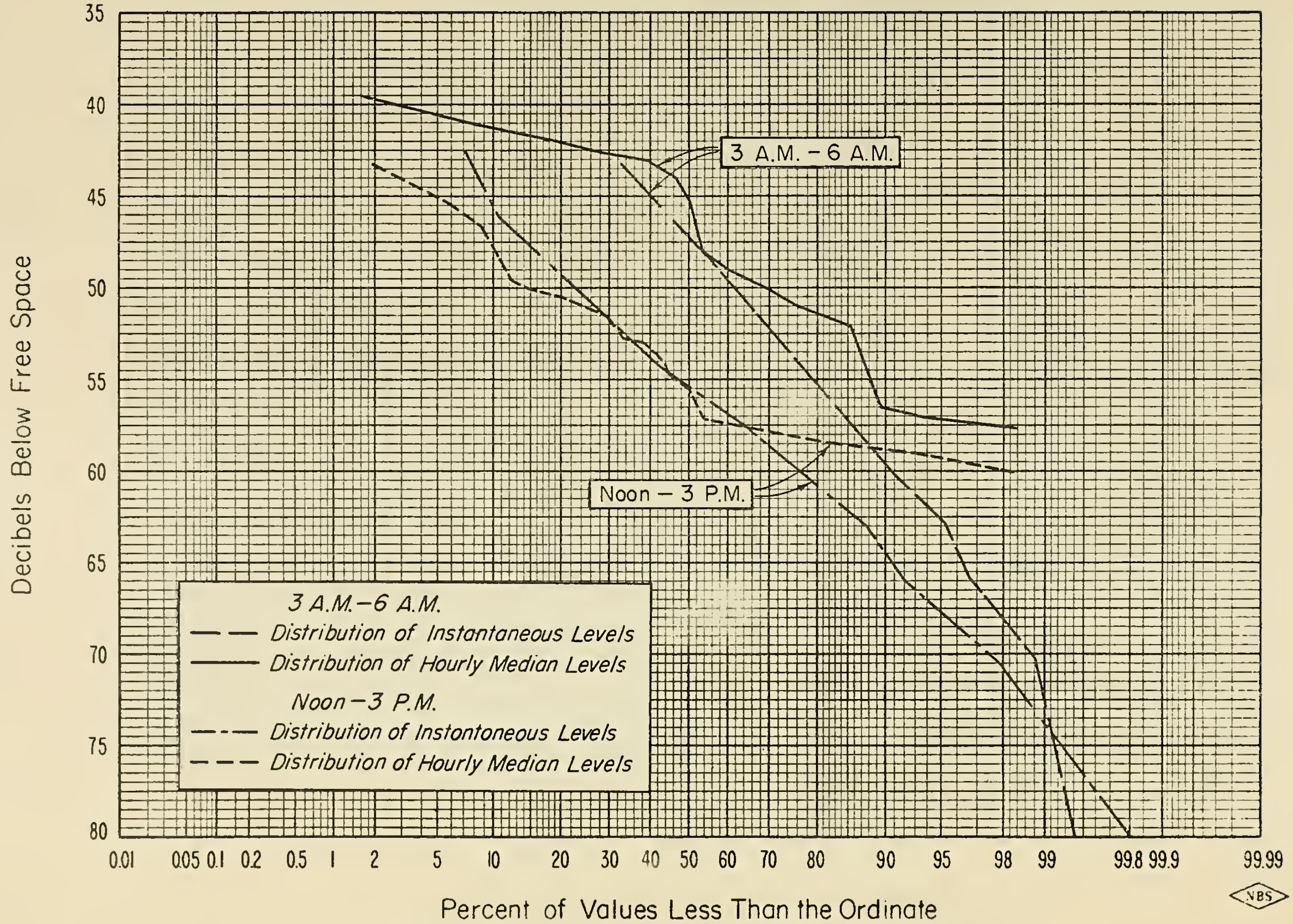


Figure 9

DISTRIBUTIONS OF INSTANTANEOUS AND HOURLY MEDIAN SIGNAL LEVELS FOR PERIOD AUGUST 13–25, 1951

Parabolic Receiving Antenna

418 Mc Cedar Rapids – Quincy Measurements

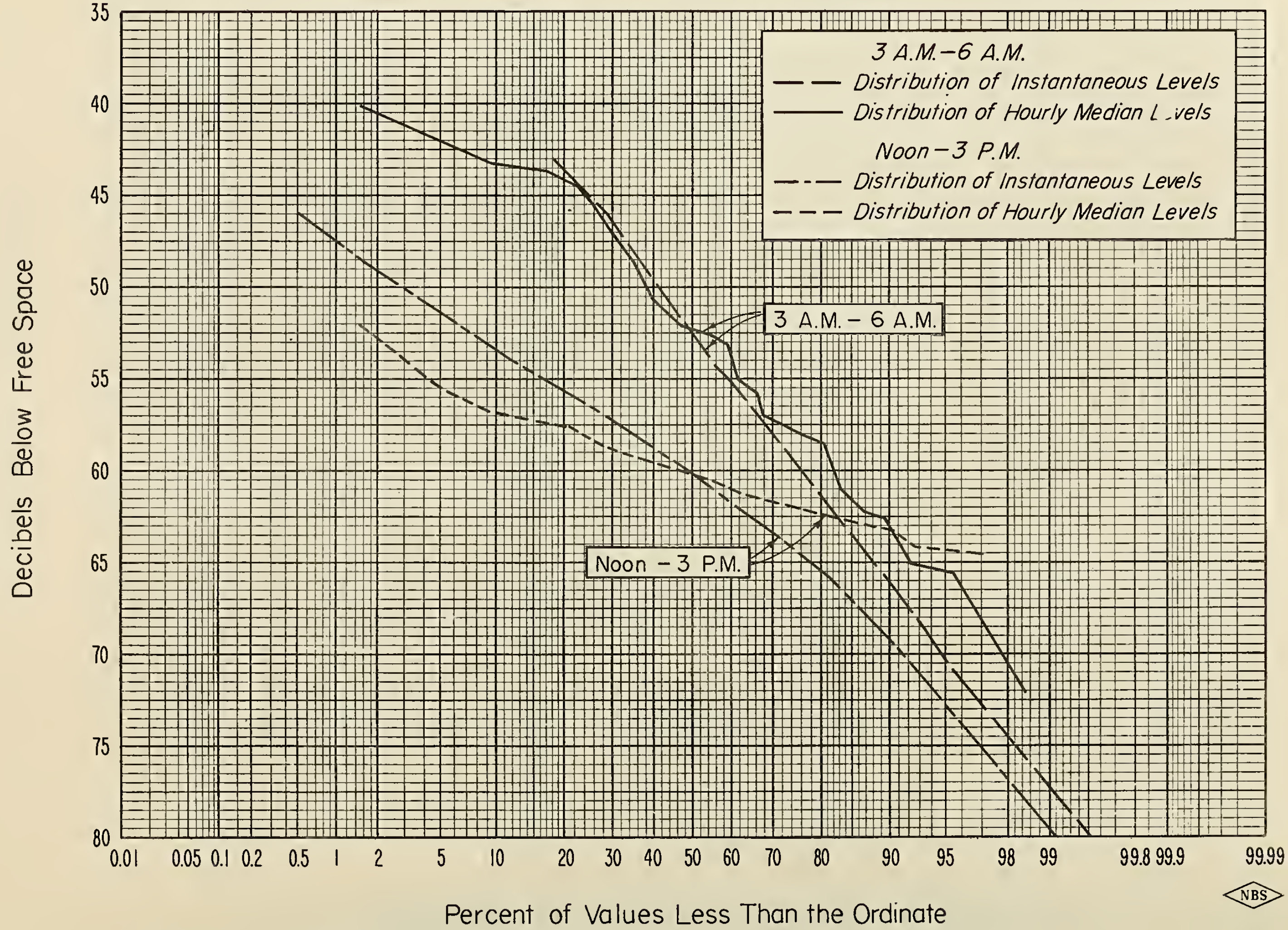


Figure 10

DISTRIBUTIONS OF INSTANTANEOUS AND HOURLY MEDIAN SIGNAL LEVELS FOR PERIOD SEPTEMBER 10-23, 1951

Parabolic Receiving Antenna

418 Mc Cedar Rapids – Quincy Measurements

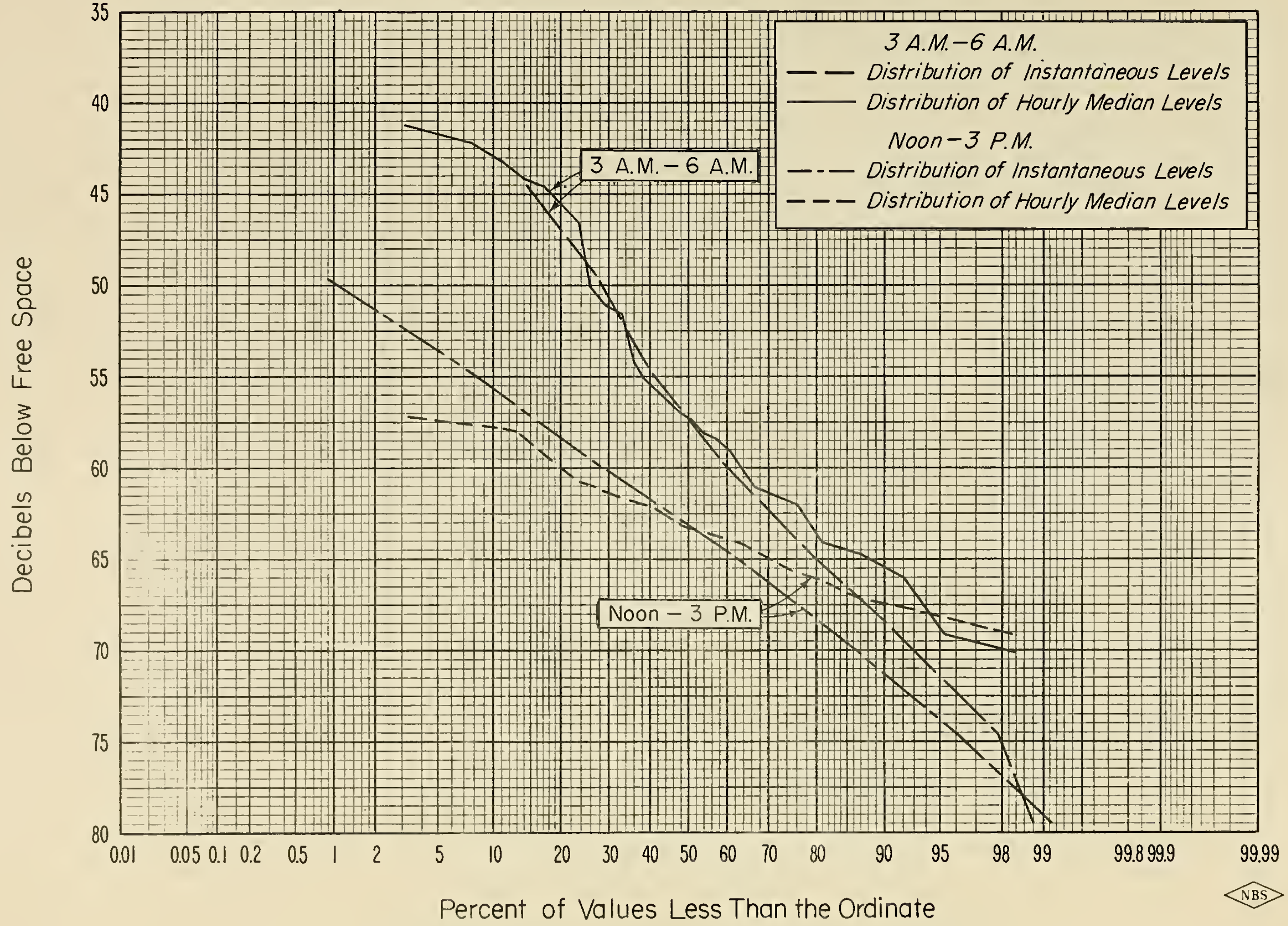


Figure 11

DISTRIBUTIONS OF INSTANTANEOUS
AND HOURLY MEDIAN SIGNAL LEVELS
FOR PERIOD OCTOBER 1–13, 1951

Parabolic Receiving Antenna
418 Mc Cedar Rapids – Quincy Measurements

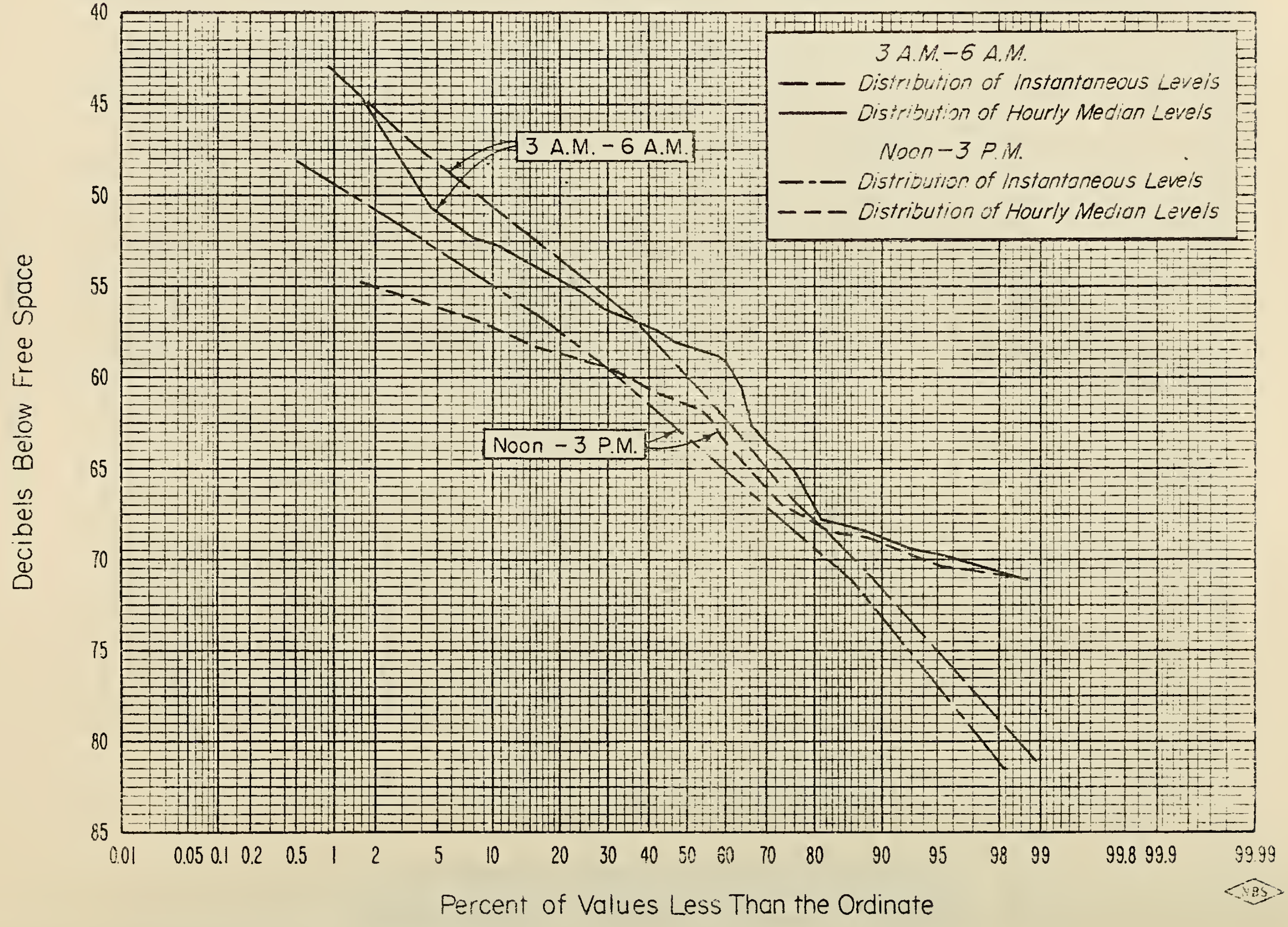


Figure 12

DISTRIBUTIONS OF INSTANTANEOUS AND HOURLY MEDIAN SIGNAL LEVELS FOR PERIOD OCTOBER 28–NOVEMBER 10, 1951

Parabolic Receiving Antenna

418 Mc Cedar Rapids–Quincy Measurements

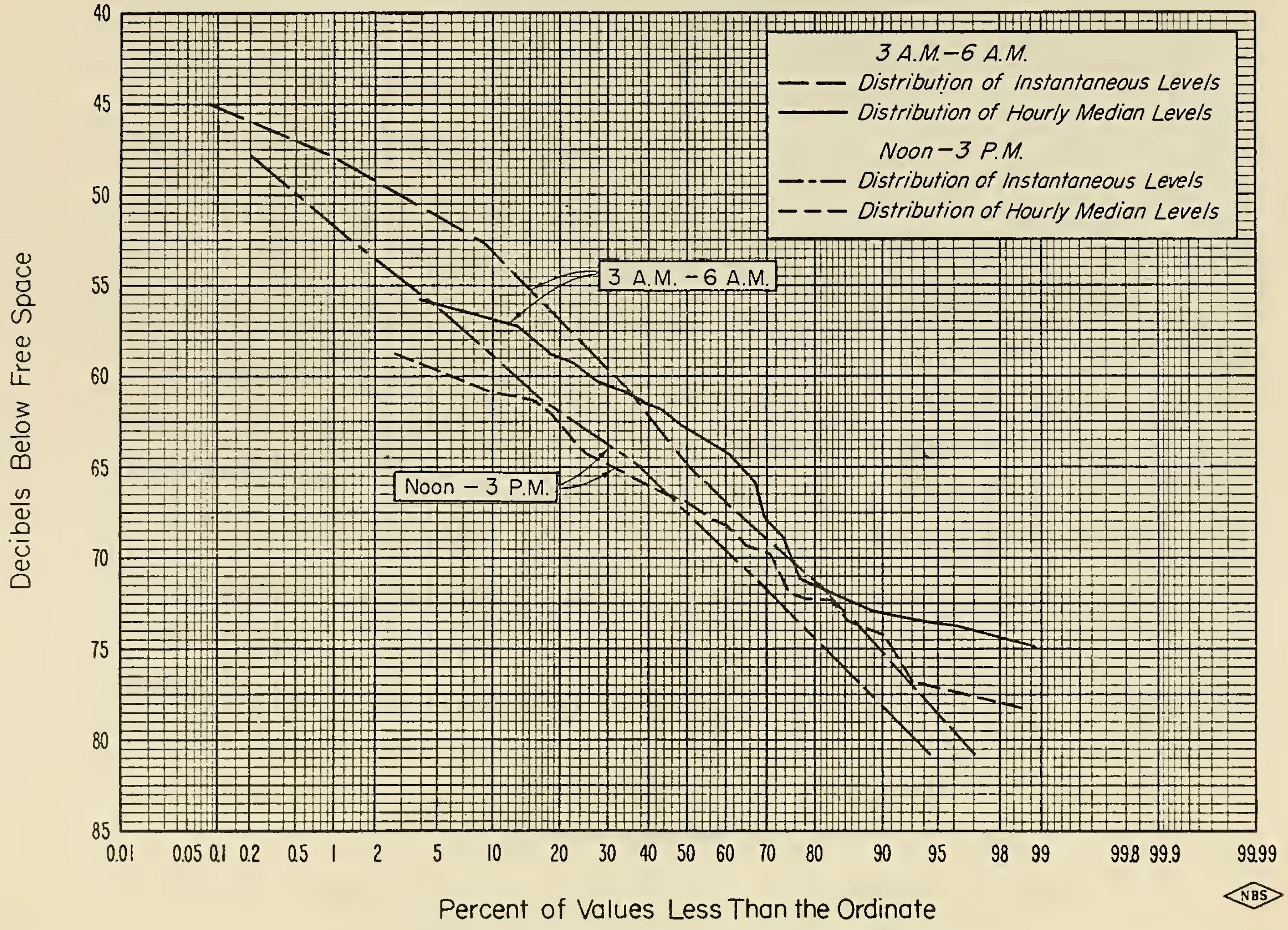


Figure 13

DISTRIBUTIONS OF INSTANTANEOUS
AND HOURLY MEDIAN SIGNAL LEVELS
FOR PERIOD NOVEMBER 26—DECEMBER 15, 1951

Parabolic Receiving Antenna

418 Mc Cedar Rapids - Quincy Measurements

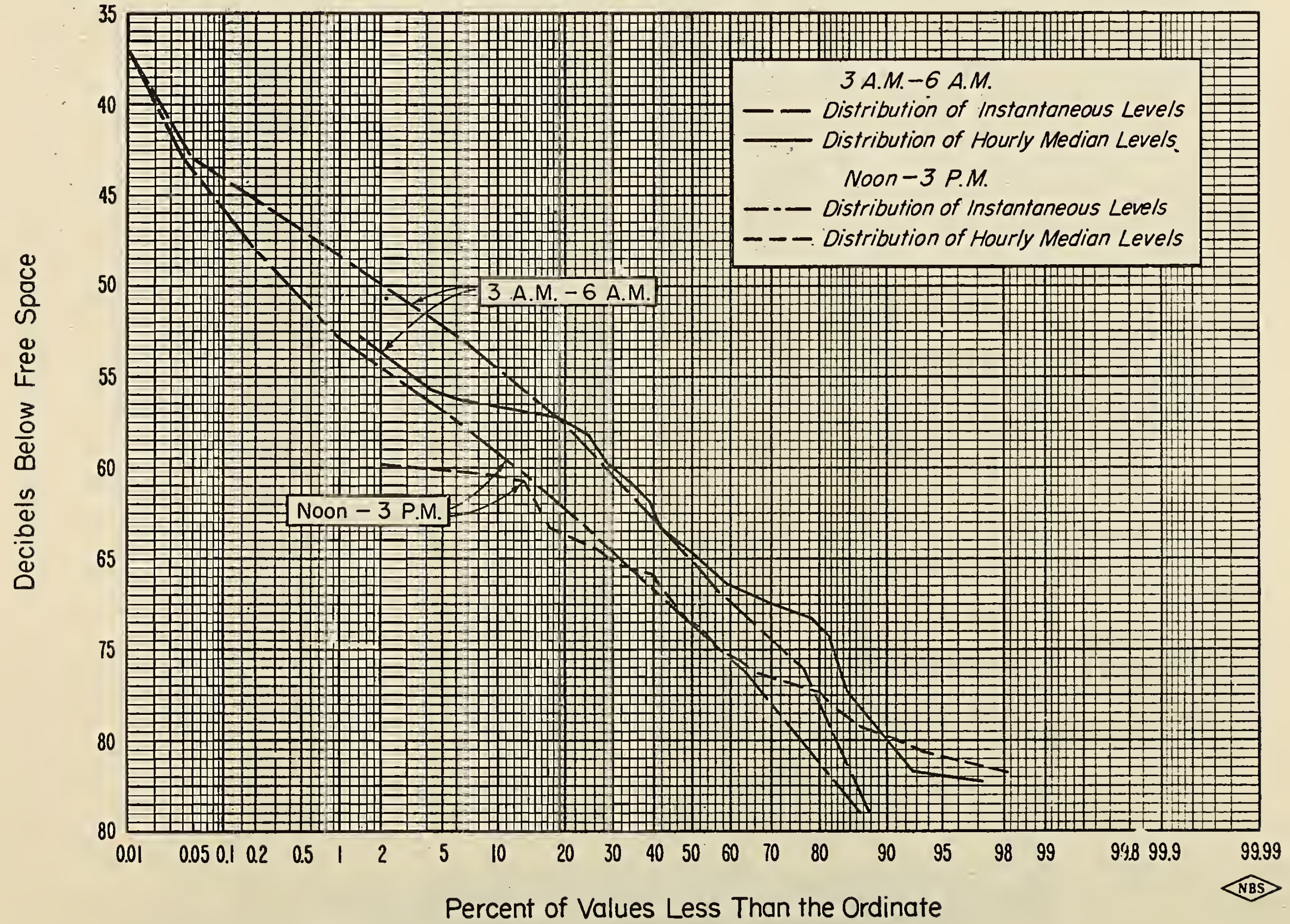


Figure 14

DISTRIBUTIONS OF INSTANTANEOUS AND HOURLY MEDIAN SIGNAL LEVELS FOR PERIOD MAY 2-27, 1951

Corner Reflector Receiving Antenna
418 Mc Cedar Rapids - Quincy Measurements

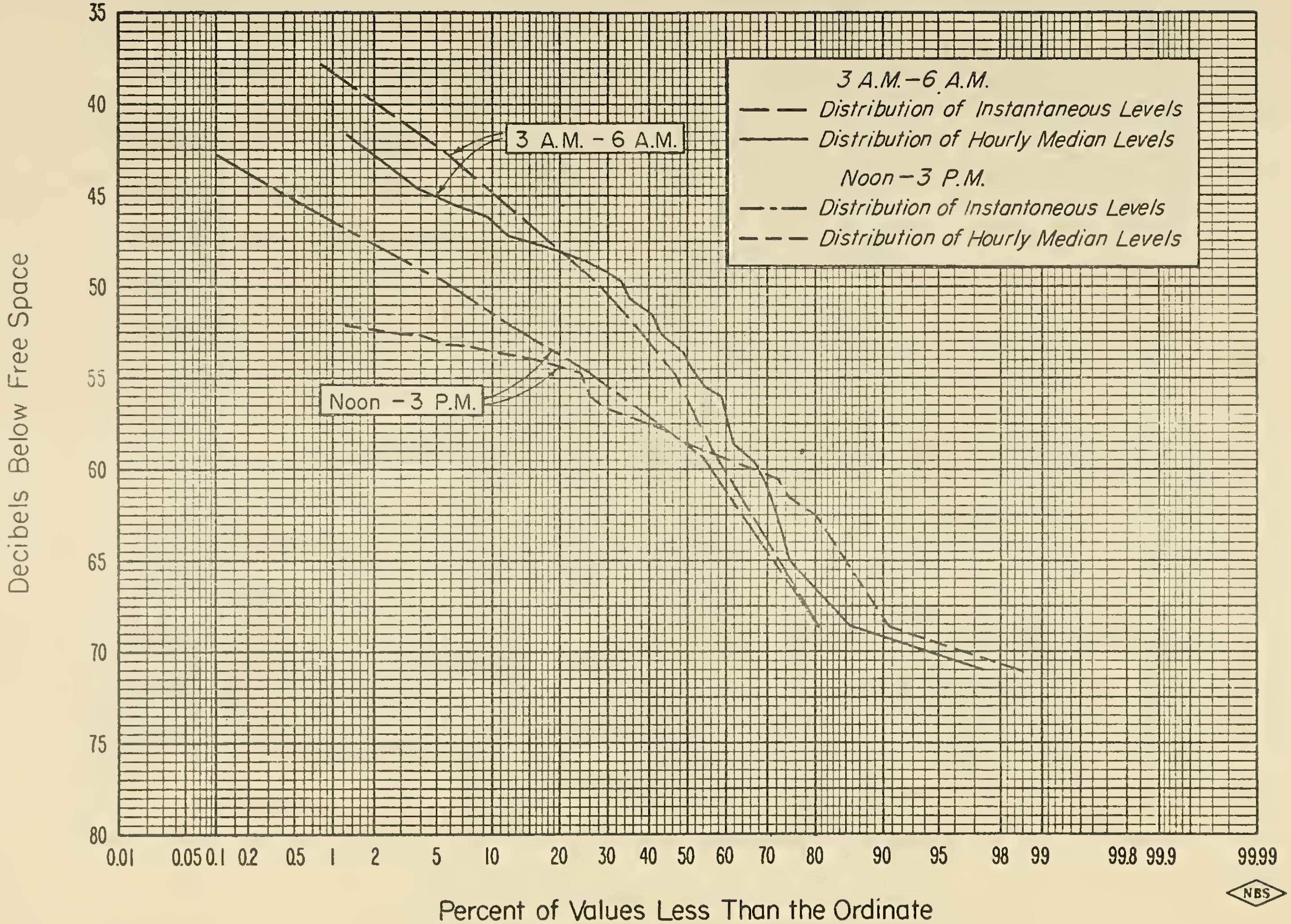


Figure 15

DISTRIBUTIONS OF INSTANTANEOUS AND HOURLY MEDIAN SIGNAL LEVELS FOR PERIOD JUNE 11–30, 1951

Corner Reflector Receiving Antenna

418 Mc Cedar Rapids–Quincy Measurements

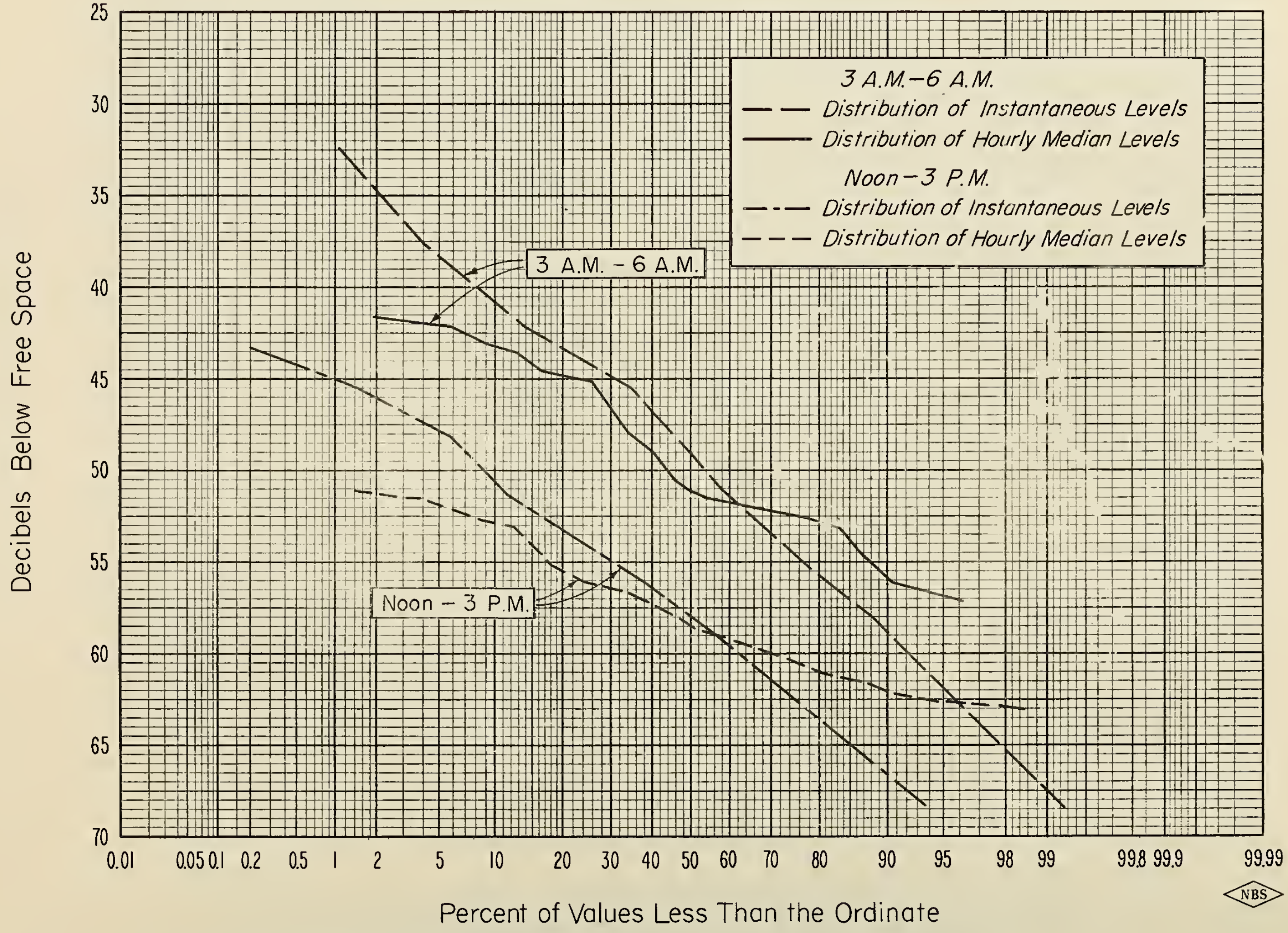


Figure 16

DISTRIBUTIONS OF INSTANTANEOUS
AND HOURLY MEDIAN SIGNAL LEVELS
FOR PERIOD JULY 24 – AUGUST 4, 1951

Corner Reflector Receiving Antenna

418 Mc Cedar Rapids – Quincy Measurements

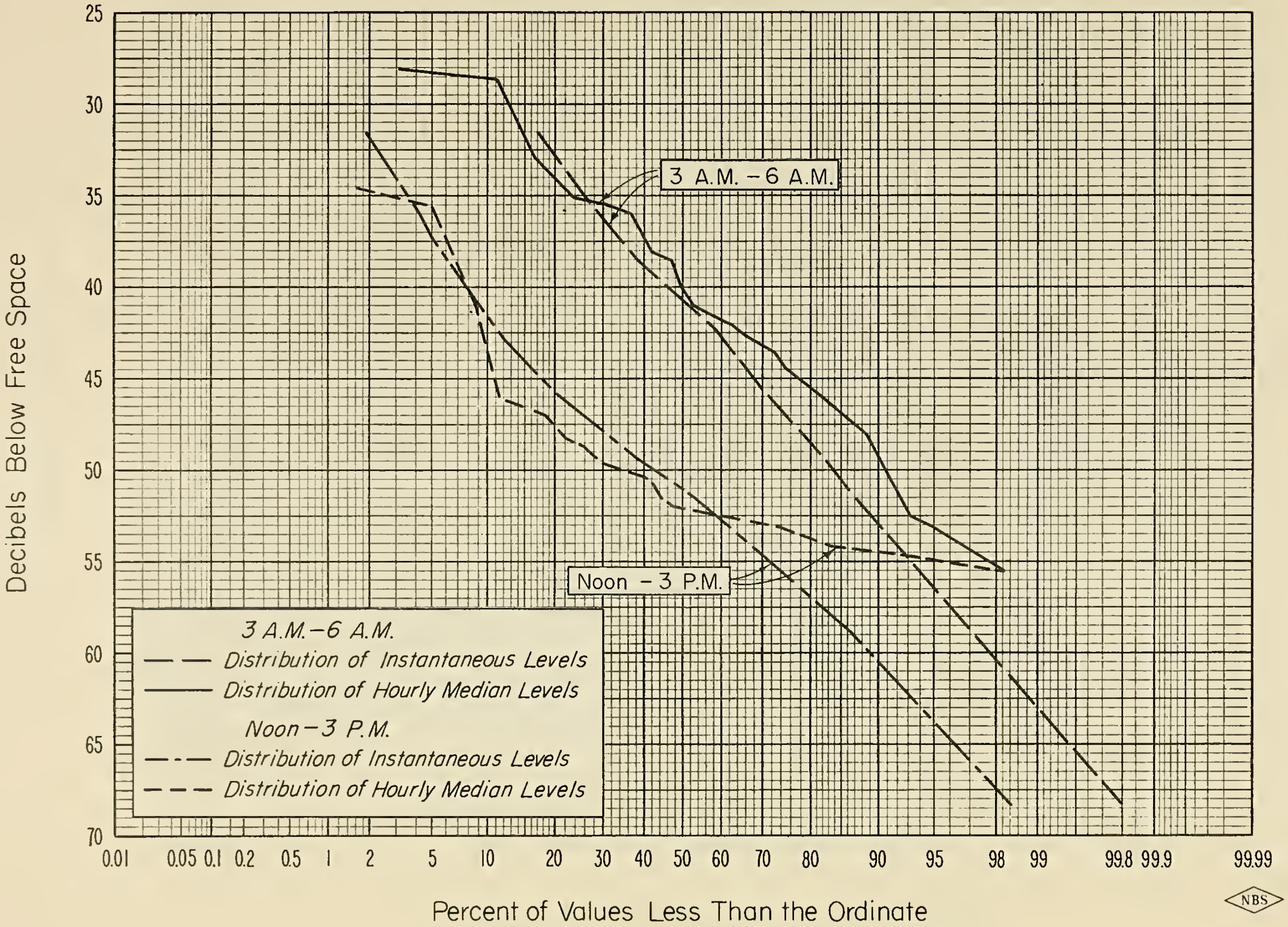


Figure 17

DISTRIBUTIONS OF INSTANTANEOUS AND HOURLY MEDIAN SIGNAL LEVELS FOR PERIOD AUGUST 13-25, 1951

Corner Reflector Receiving Antenna

418 Mc Cedar Rapids - Quincy Measurements

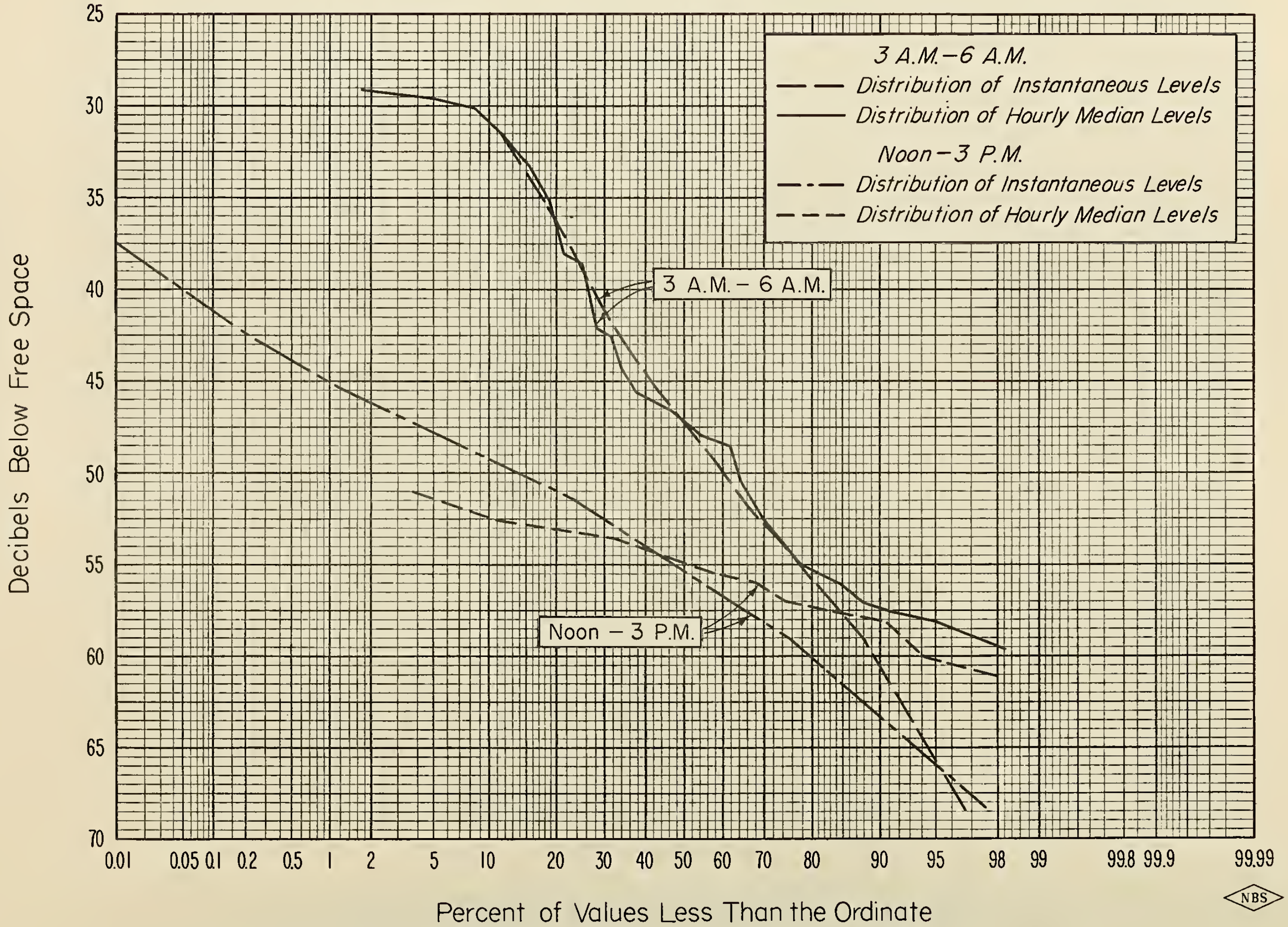


Figure 18

DISTRIBUTIONS OF INSTANTANEOUS AND HOURLY MEDIAN SIGNAL LEVELS FOR PERIOD SEPTEMBER 11–23, 1951

Corner Reflector Receiving Antenna

418 Mc Cedar Rapids – Quincy Measurements

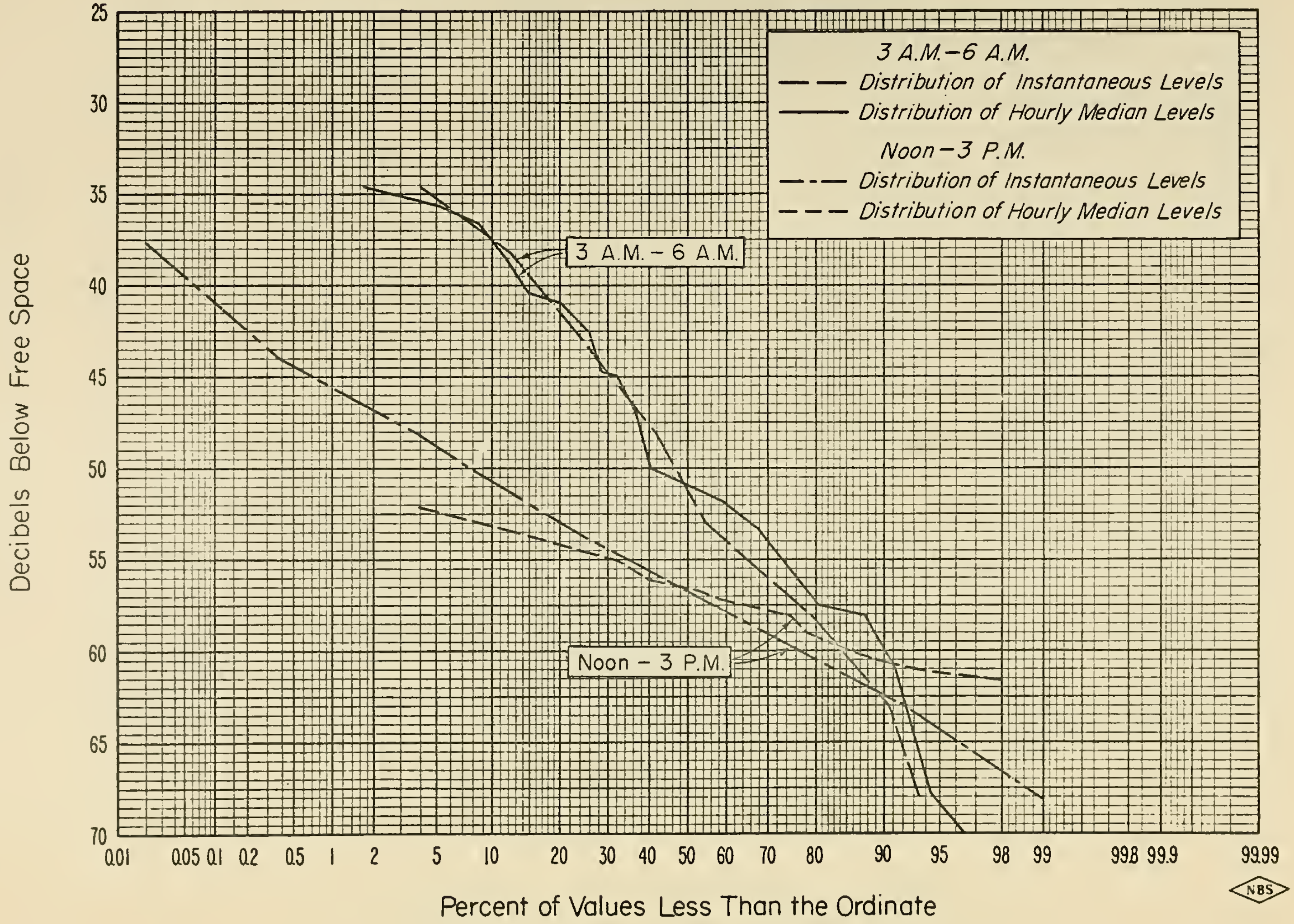


Figure 19

DISTRIBUTIONS OF INSTANTANEOUS AND HOURLY MEDIAN SIGNAL LEVELS FOR PERIOD OCTOBER 1-13, 1951

Corner Reflector Receiving Antenna

418 Mc Cedar Rapids – Quincy Measurements

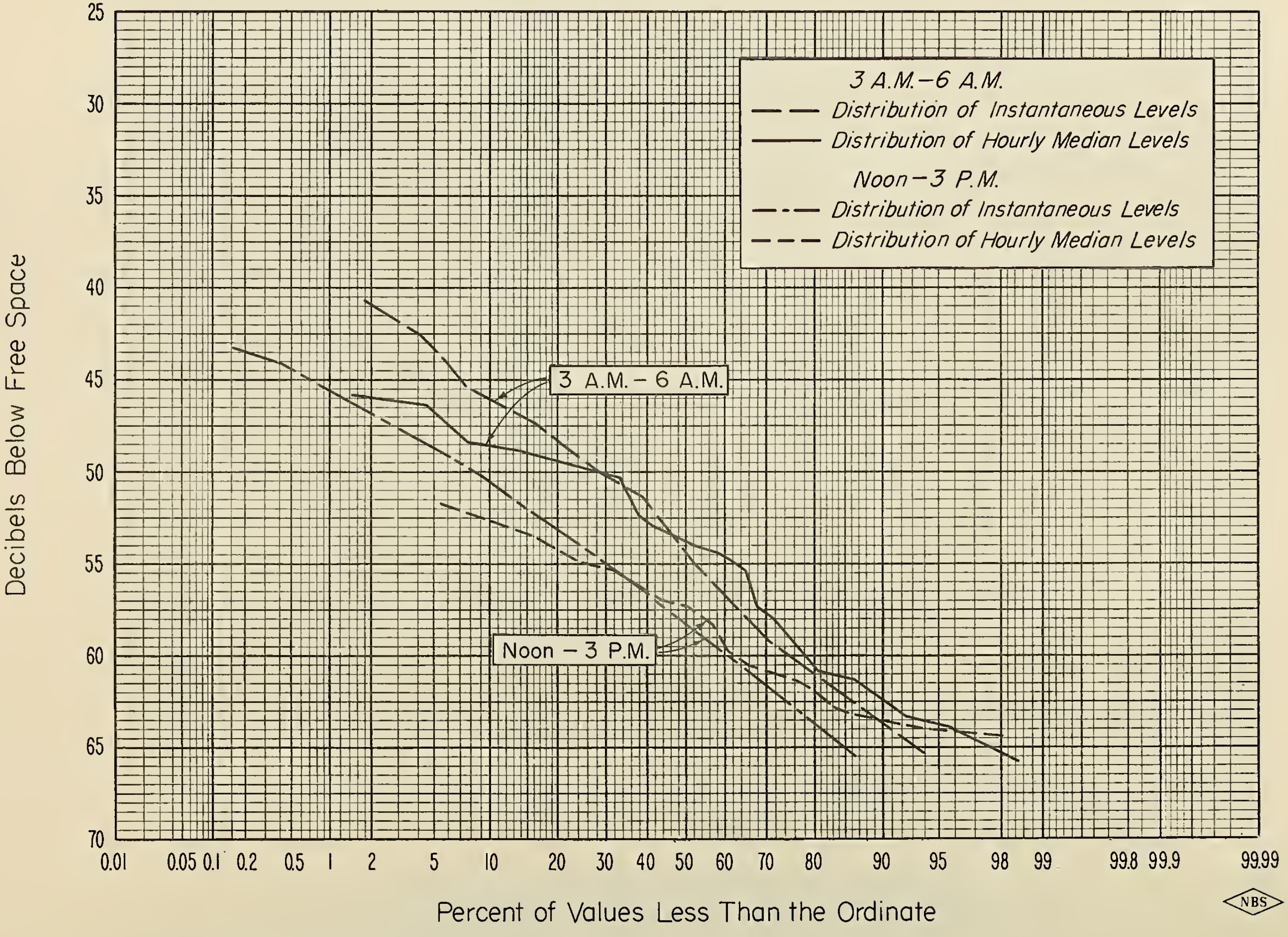


Figure 20

DISTRIBUTIONS OF INSTANTANEOUS
AND HOURLY MEDIAN SIGNAL LEVELS
FOR PERIOD OCTOBER 28-NOVEMBER 10, 1951

Corner Reflector Receiving Antenna
418 Mc Cedar Rapids-Quincy Measurements

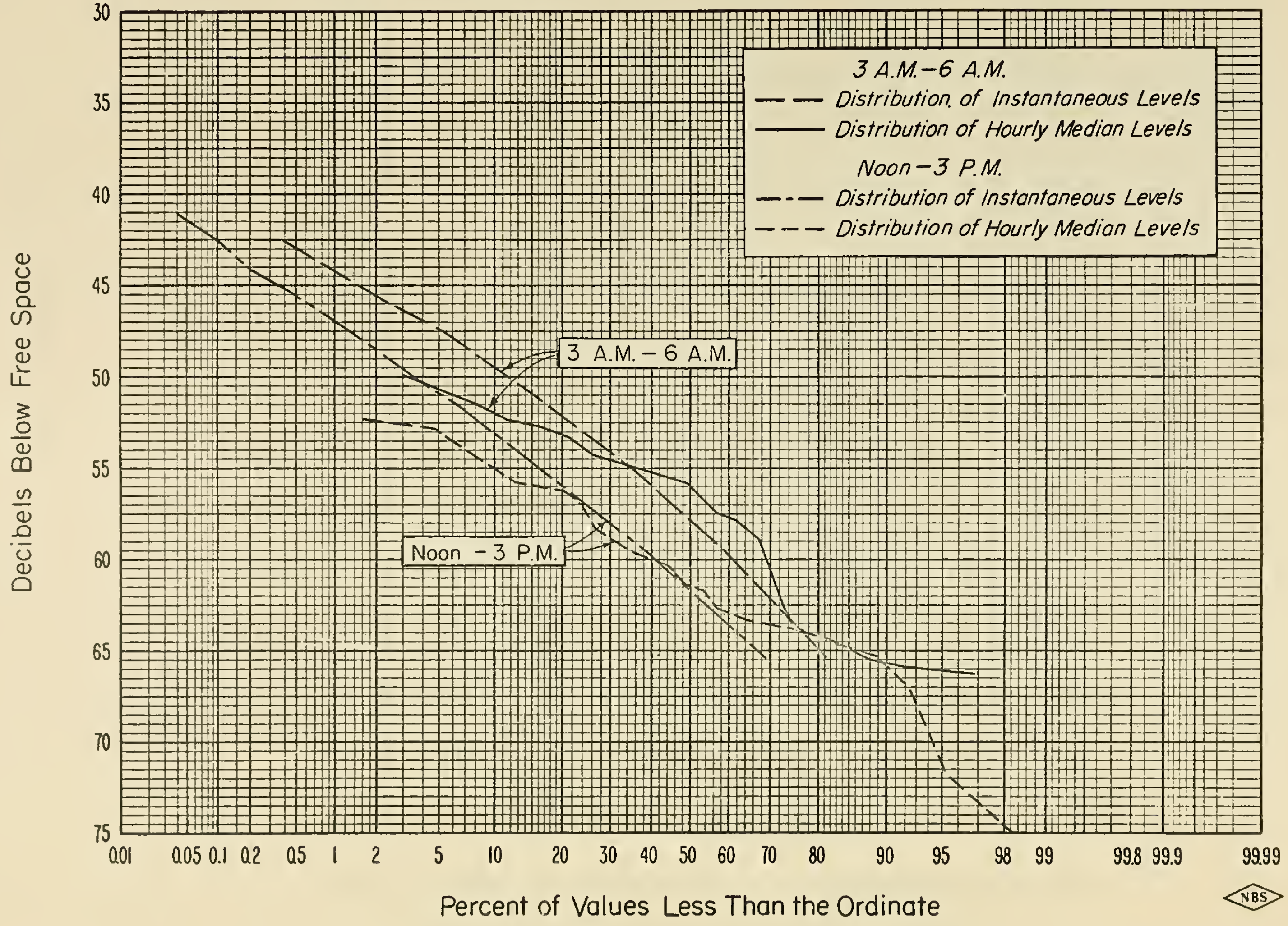


Figure 21

DISTRIBUTIONS OF INSTANTANEOUS AND HOURLY MEDIAN SIGNAL LEVELS FOR PERIOD NOVEMBER 26 - DECEMBER 10, 1951

Corner Reflector Receiving Antenna

418 Mc Cedar Rapids - Quincy Measurements

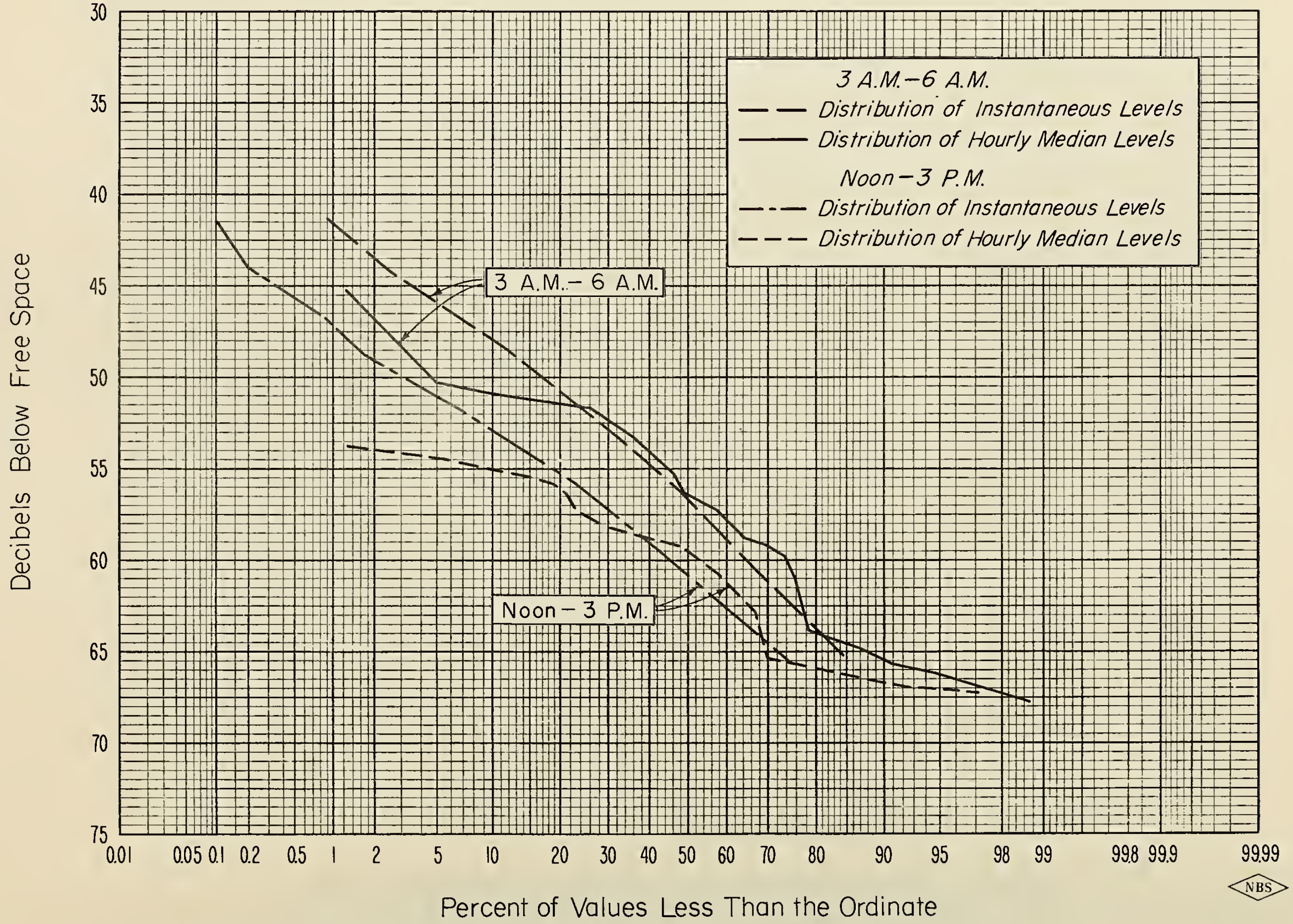


Figure 22

DISTRIBUTIONS OF INSTANTANEOUS
SIGNAL LEVELS
FOR PERIOD APRIL 30-DECEMBER 15, 1951

Parabolic Receiving Antenna

418 Mc Cedar Rapids - Quincy Measurements

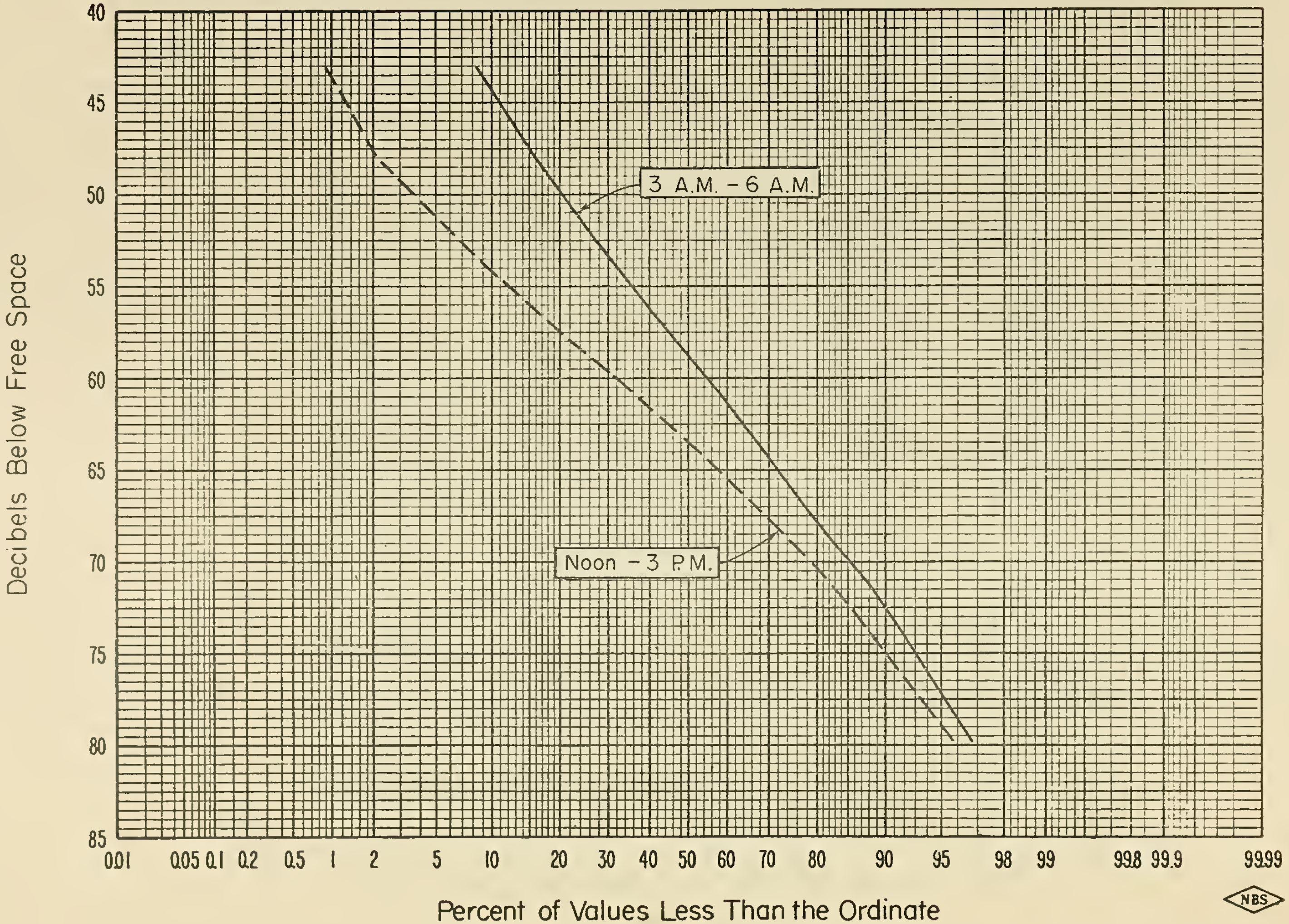
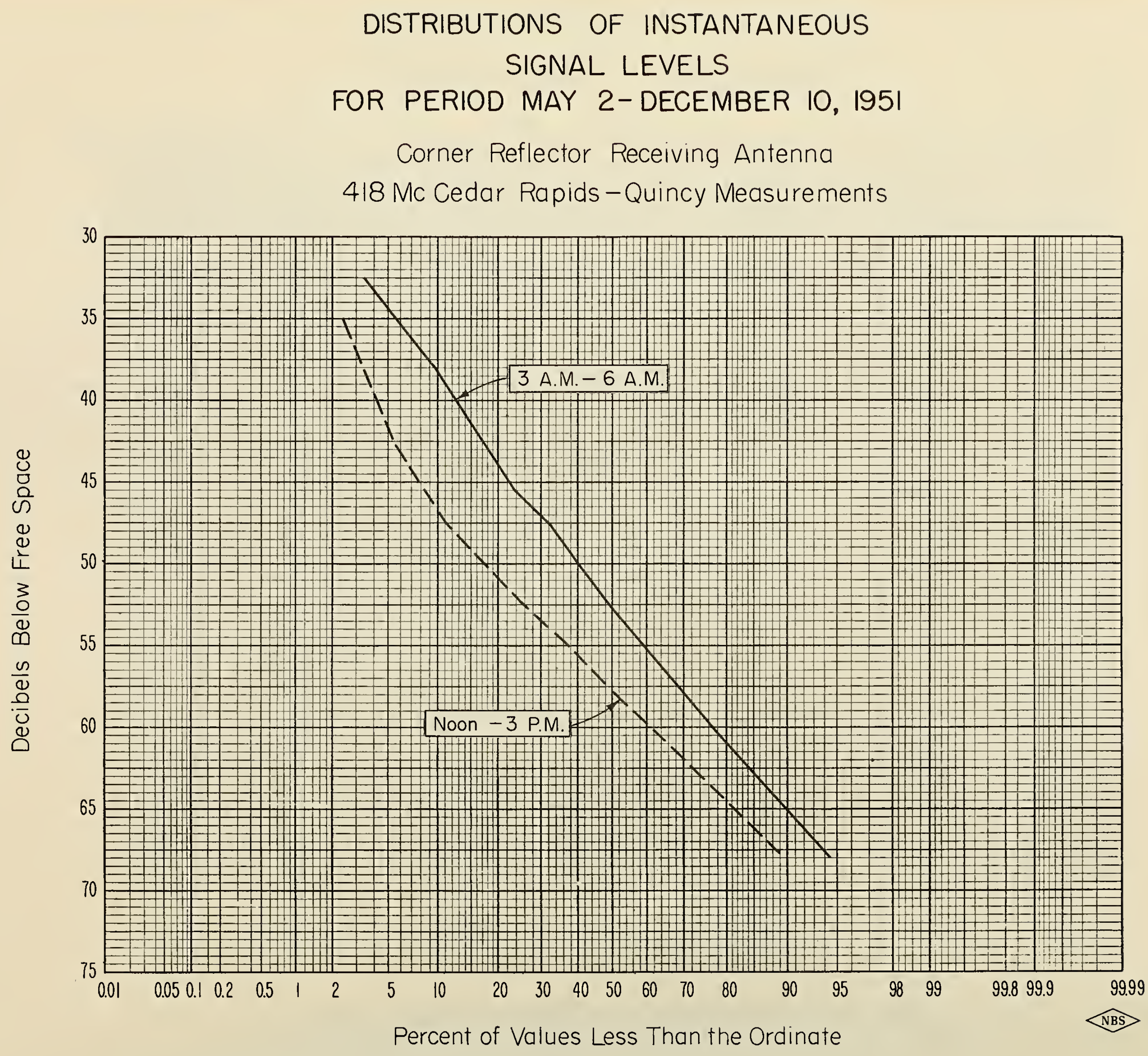


Figure 23



DISTRIBUTIONS OF INSTANTANEOUS
SIGNAL LEVELS
FOR PERIOD MAY 2-DECEMBER 10, 1951
Corner Reflector Receiving Antenna
418 Mc Cedar Rapids-Quincy Measurements
3 A.M. - 6 A.M.
Noon - 3 P.M.
Decibels Below Free Space
30
35
40
45
50
55
60
65
70
75
0.01
0.05
0.1
0.2
0.5
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99.8
99.9
99.99
Percent of Values Less Than the Ordinate
NBS

Figure 24

DISTRIBUTION OF HOURLY MEDIAN SIGNAL LEVELS
FOR ALL HOURS
FOR PERIOD APRIL 30-MAY 27, 1951

418 Mc Cedar Rapids, Iowa - Quincy, Illinois Measurements

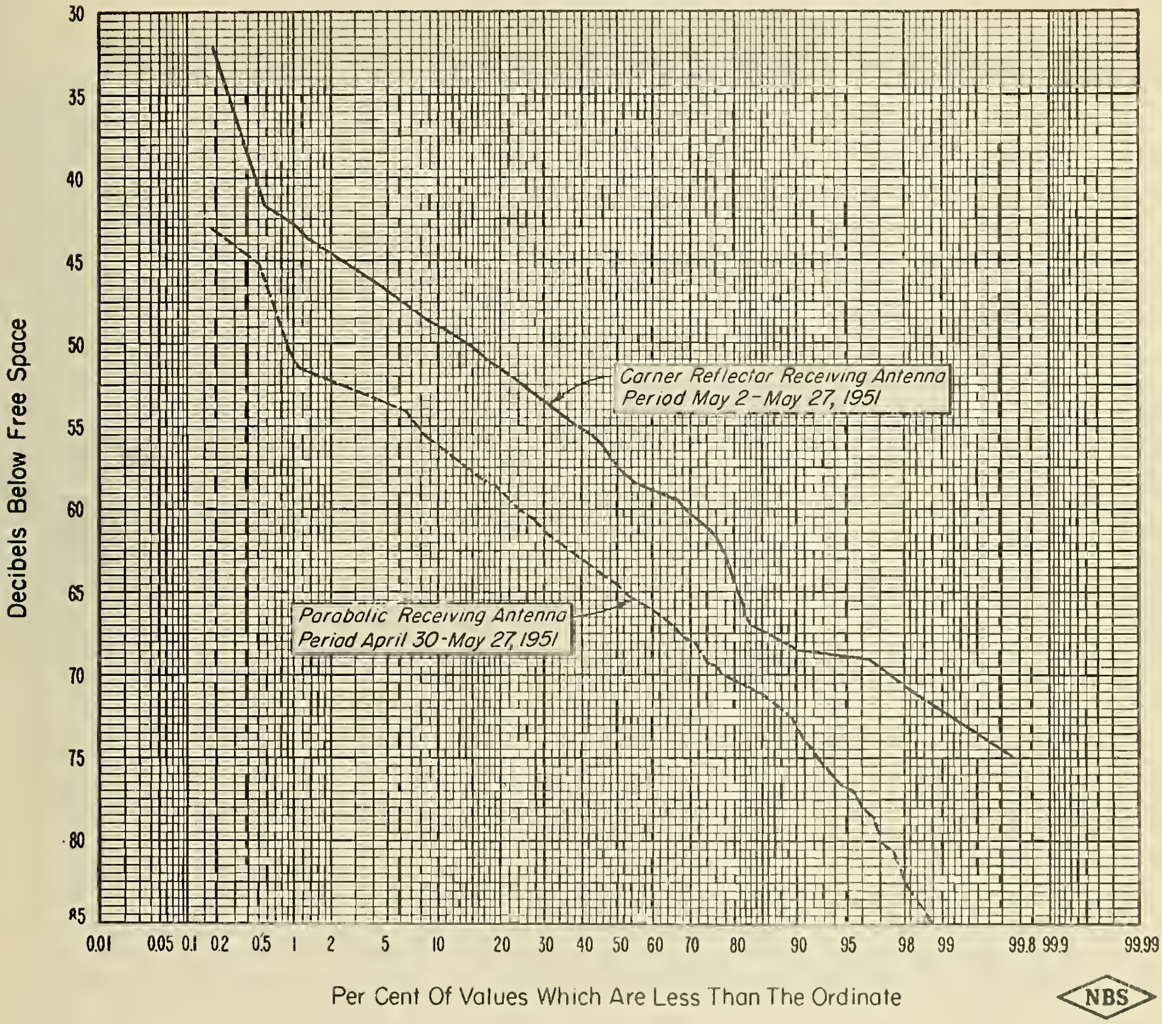


Figure 25

DISTRIBUTION OF HOURLY MEDIAN SIGNAL LEVELS
FOR ALL HOURS
FOR PERIOD JUNE 11 - 30, 1951

418 Mc Cedar Rapids, Iowa - Quincy, Illinois Measurements

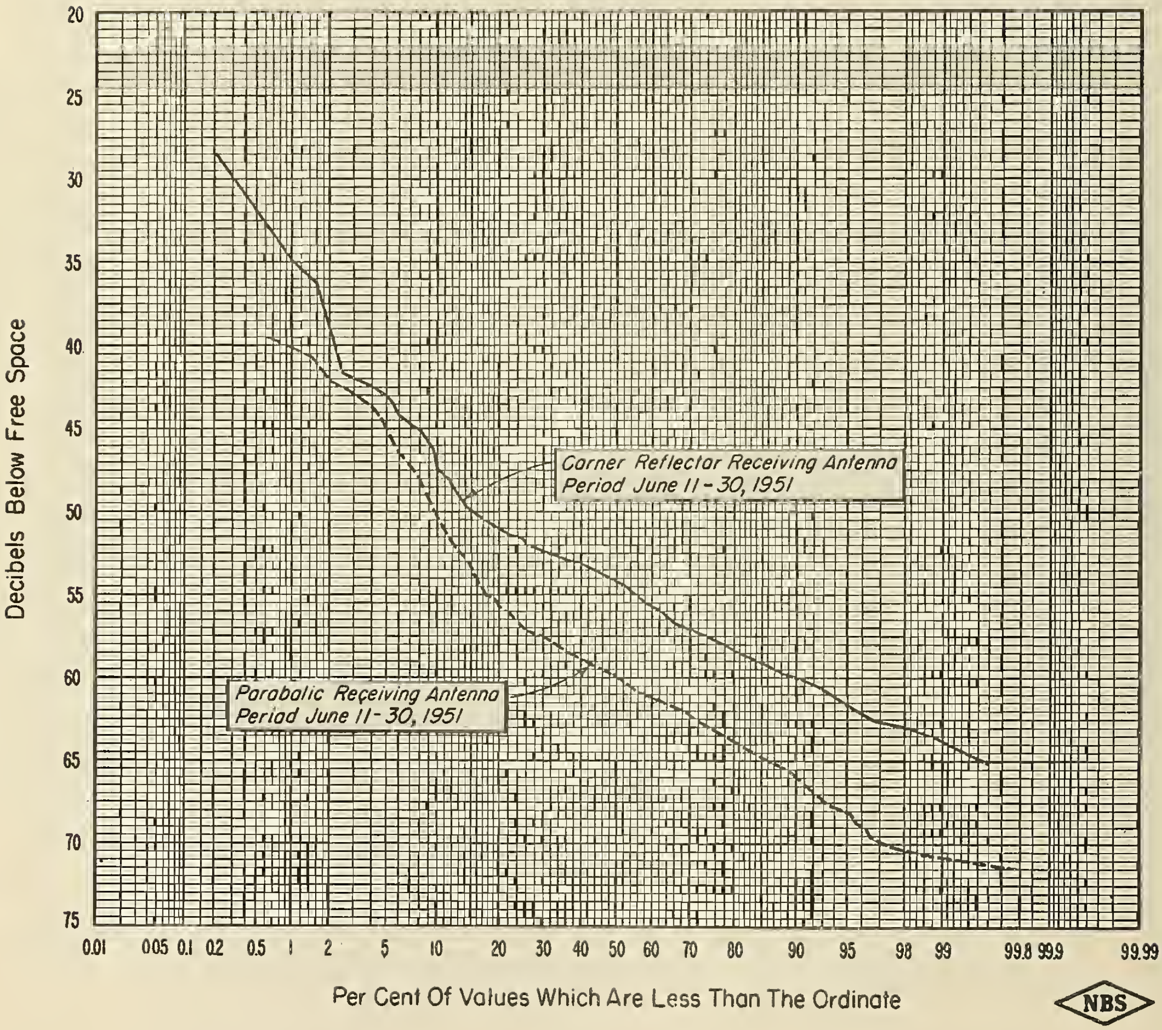


Figure 26

DISTRIBUTION OF HOURLY MEDIAN SIGNAL LEVELS
FOR ALL HOURS
FOR PERIOD JULY 24-AUGUST 4, 1951

418 Mc Cedar Rapids, Iowa - Quincy, Illinois Measurements

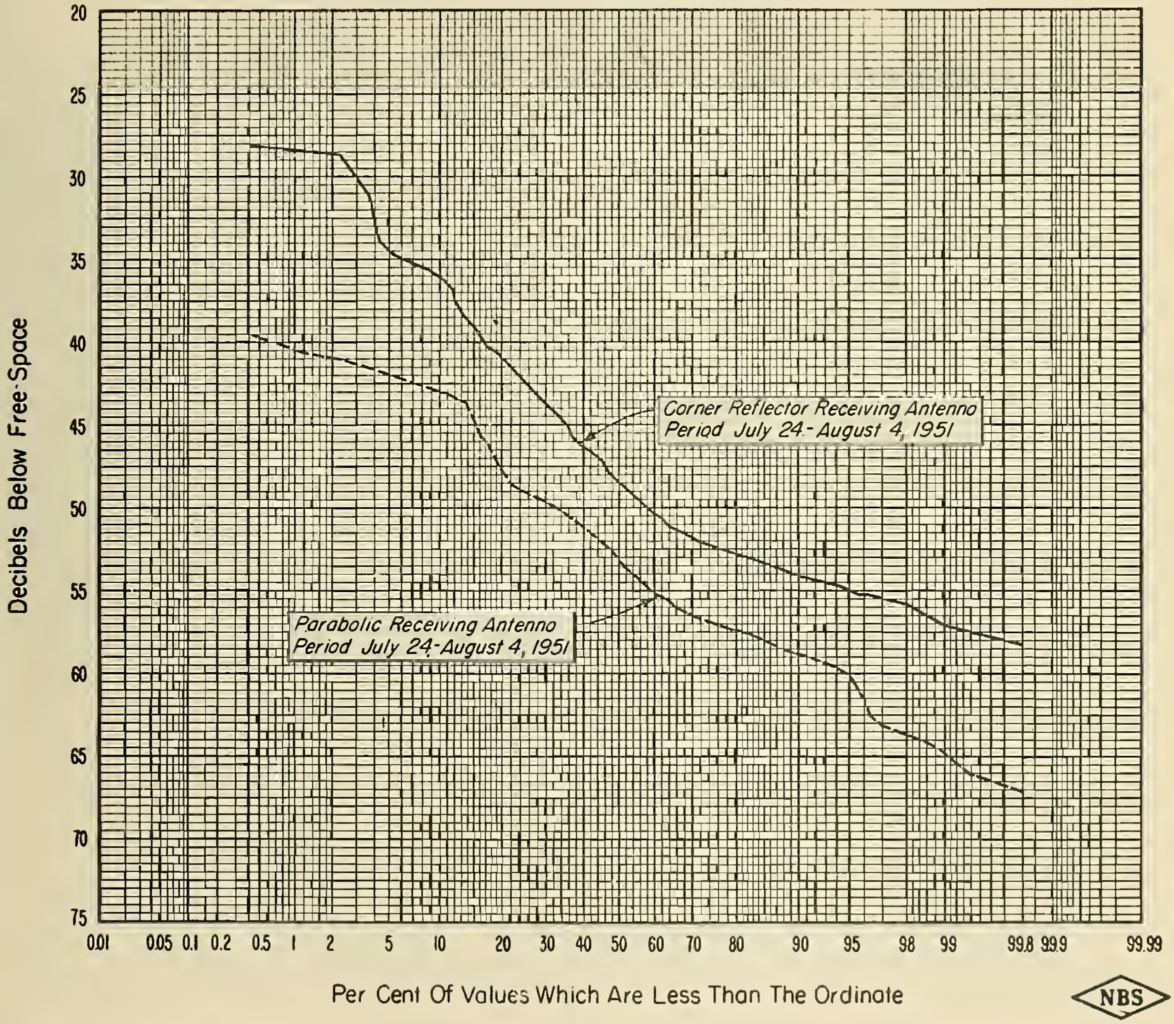


Figure 27

DISTRIBUTION OF HOURLY MEDIAN SIGNAL LEVELS
FOR ALL HOURS
FOR PERIOD AUGUST 13-25, 1951

418 Mc Cedar Rapids, Iowa - Quincy, Illinois Measurements

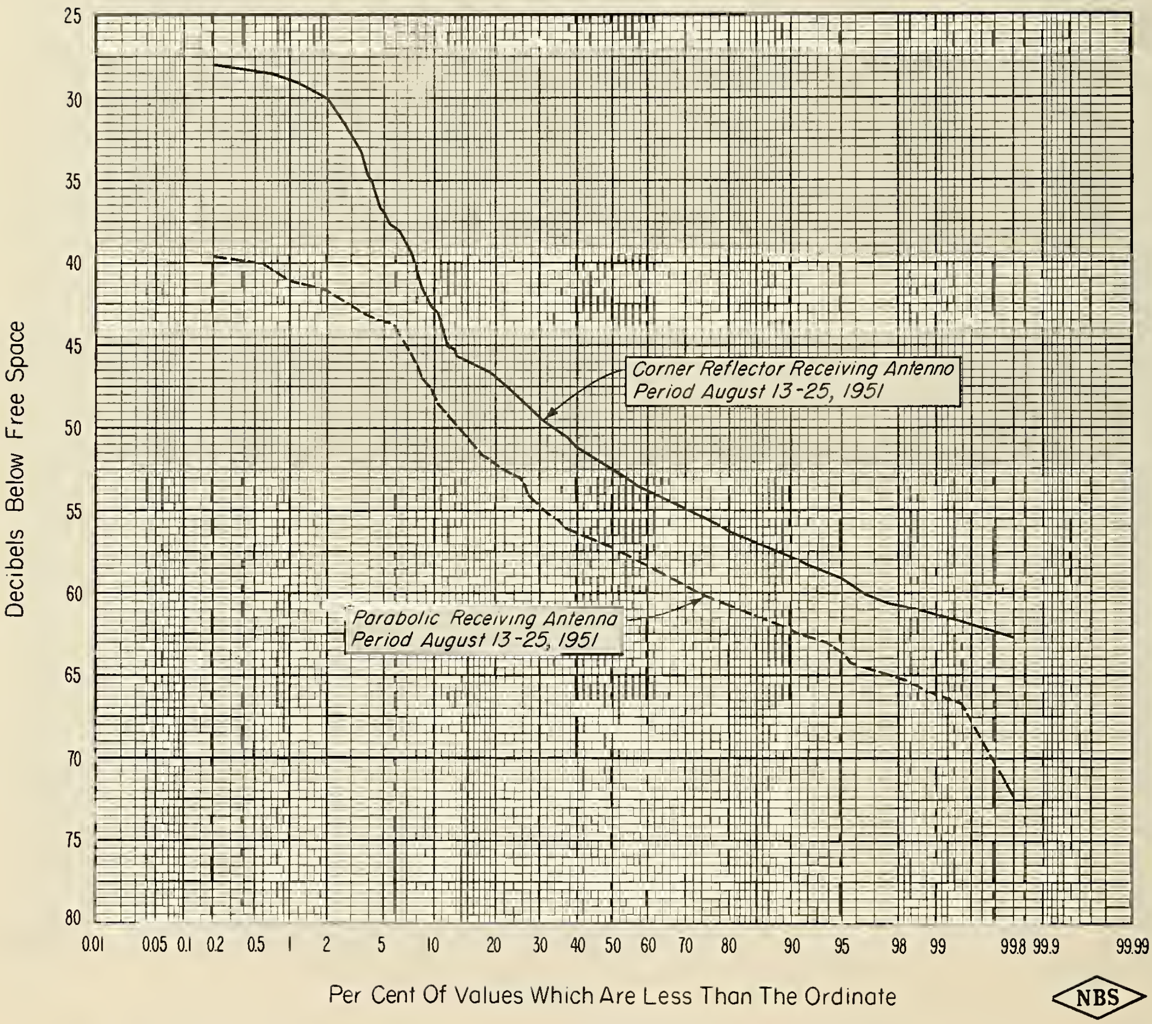


Figure 28

DISTRIBUTION OF HOURLY MEDIAN SIGNAL LEVELS
FOR ALL HOURS
FOR PERIOD SEPTEMBER 10 - 23, 1951

418 Mc Cedar Rapids, Iowa - Quincy, Illinois Measurements

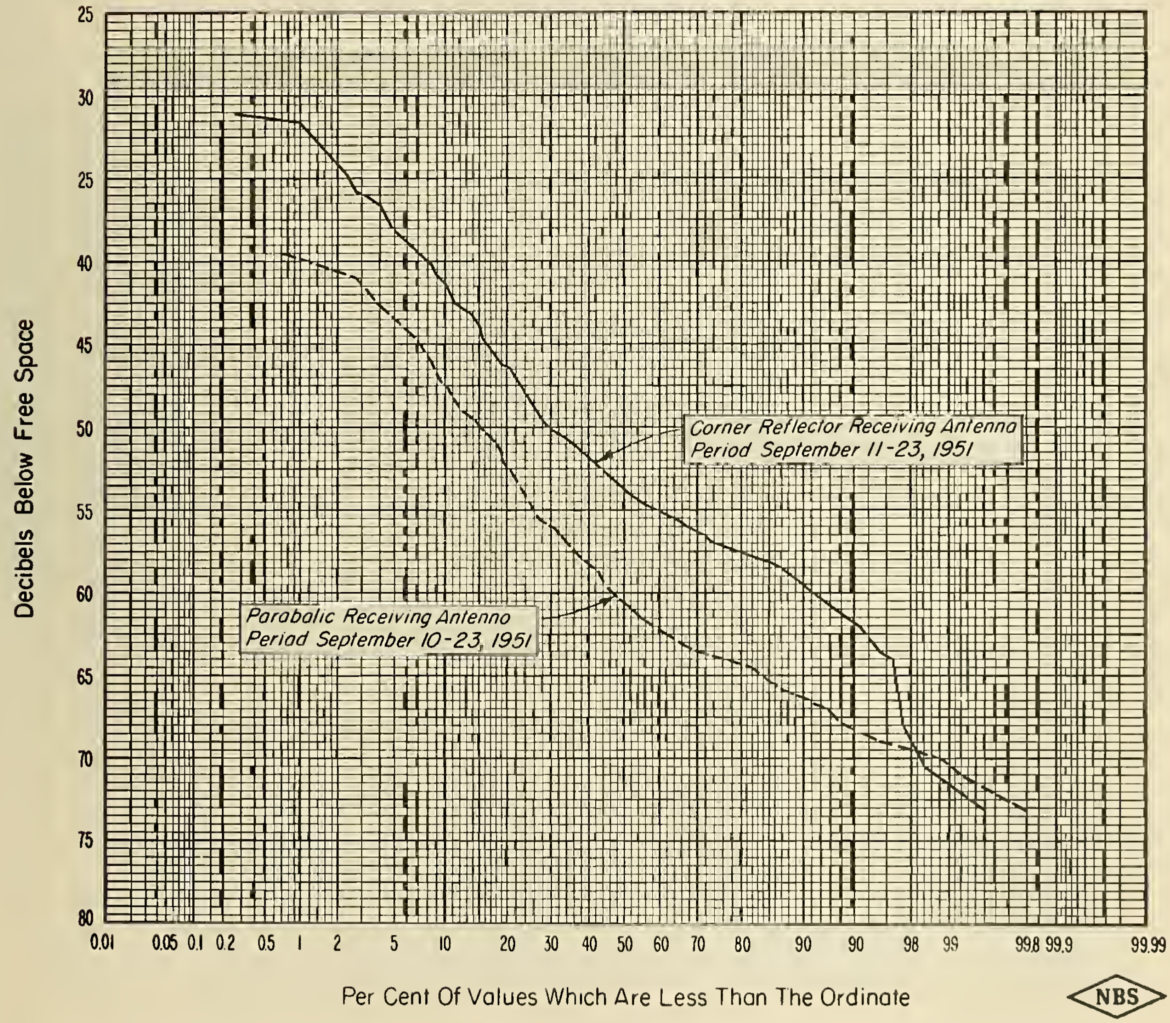


Figure 29

DISTRIBUTION OF HOURLY MEDIAN SIGNAL LEVELS
FOR ALL HOURS
FOR PERIOD OCTOBER 1-13, 1951

418 Mc Cedar Rapids, Iowa - Quincy, Illinois Measurements

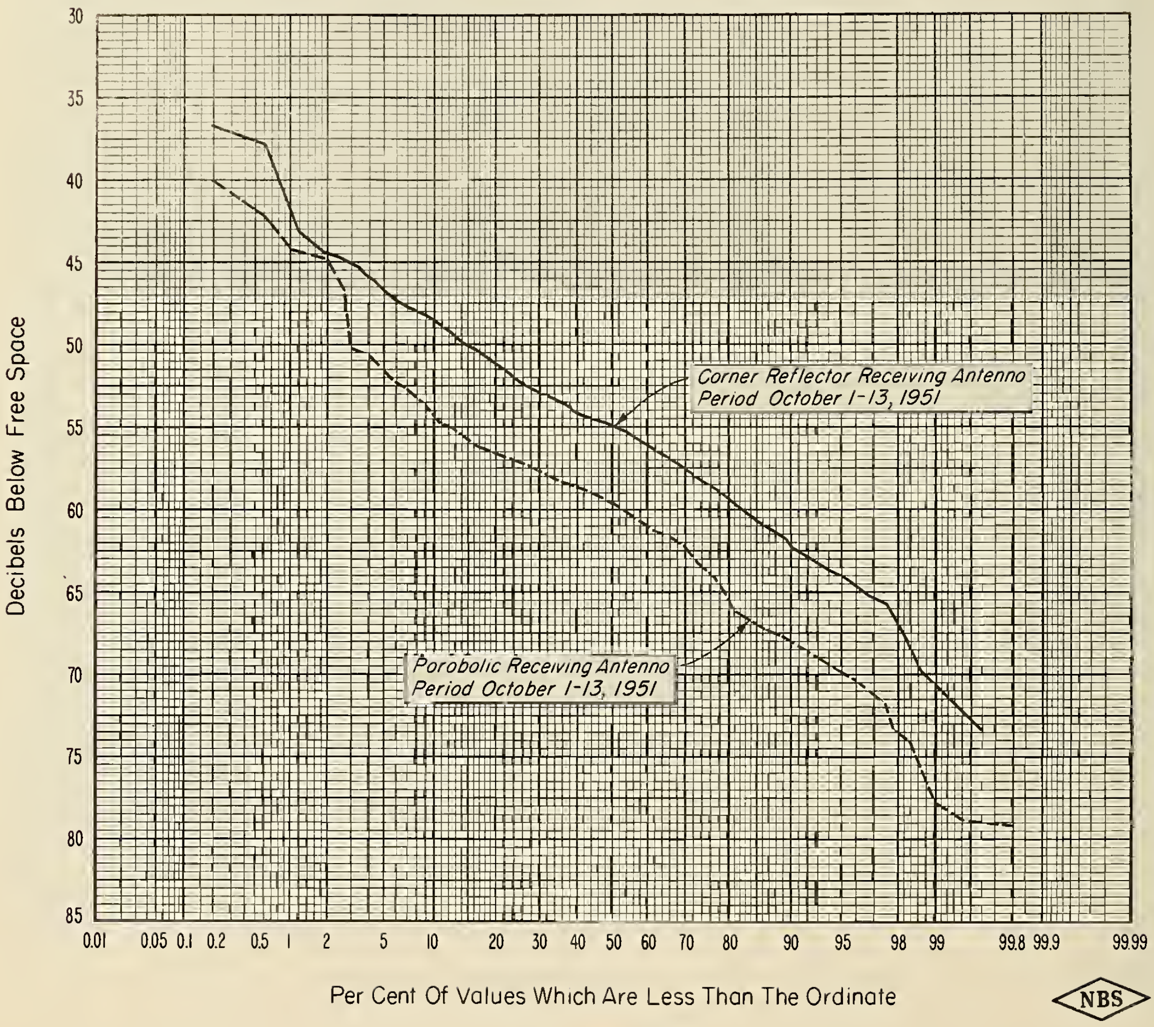


Figure 30

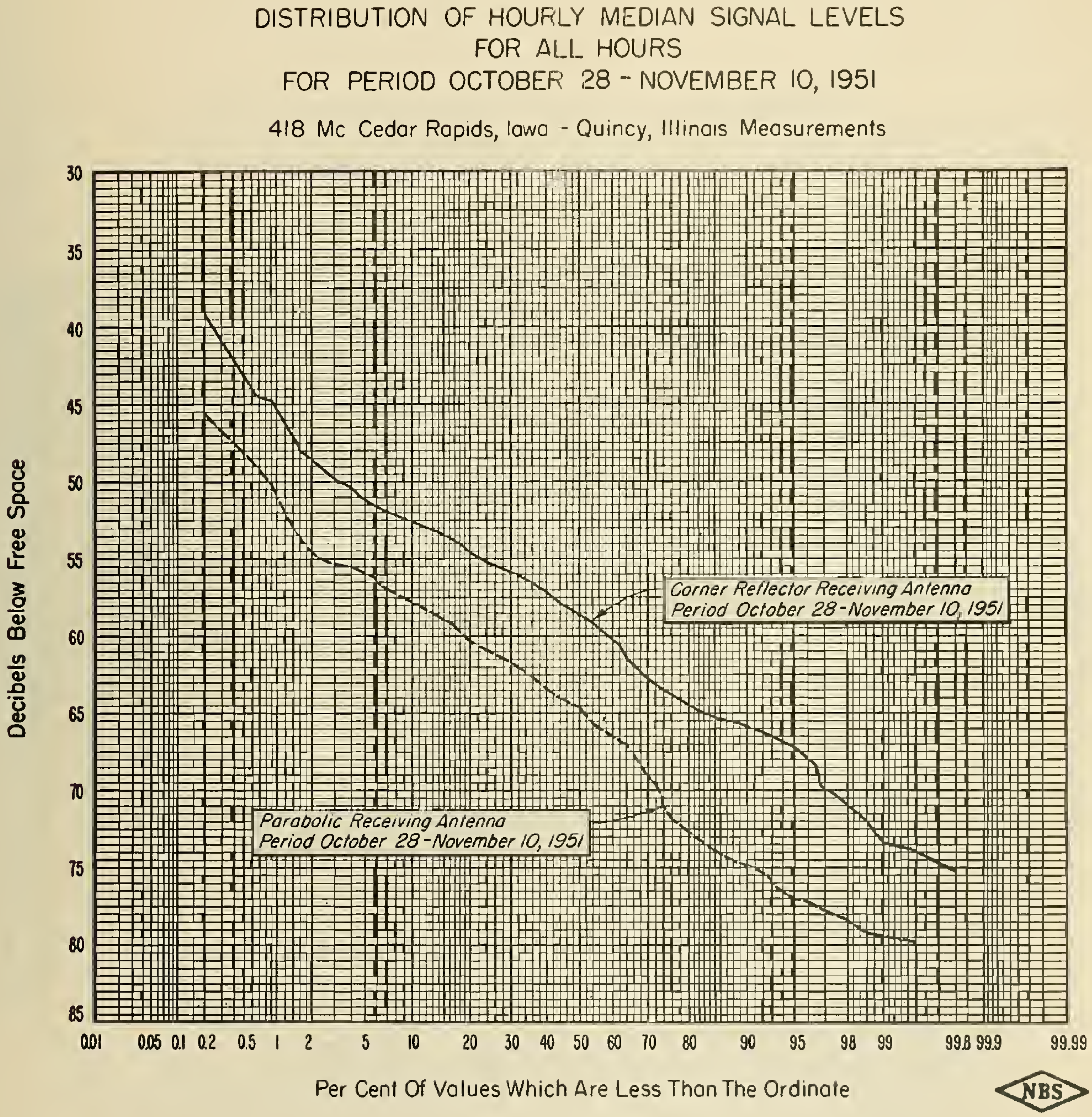

DISTRIBUTION OF HOURLY MEDIAN SIGNAL LEVELS
FOR ALL HOURS
FOR PERIOD OCTOBER 28 - NOVEMBER 10, 1951
418 Mc Cedar Rapids, Iowa - Quincy, Illinois Measurements
Decibels Below Free Space
30
35
40
45
50
55
60
65
70
75
80
85
0.01
0.05
0.1
0.2
0.5
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99.8
99.9
99.99
Corner Reflector Receiving Antenna
Period October 28-November 10, 1951
Parabolic Receiving Antenna
Period October 28-November 10, 1951
Per Cent Of Values Which Are Less Than The Ordinate
NBS

Figure 31

DISTRIBUTION OF HOURLY MEDIAN SIGNAL LEVELS
FOR ALL HOURS
FOR PERIOD NOVEMBER 26-DECEMBER 15, 1951

418 Mc Cedar Rapids, Iowa - Quincy, Illinois Measurements

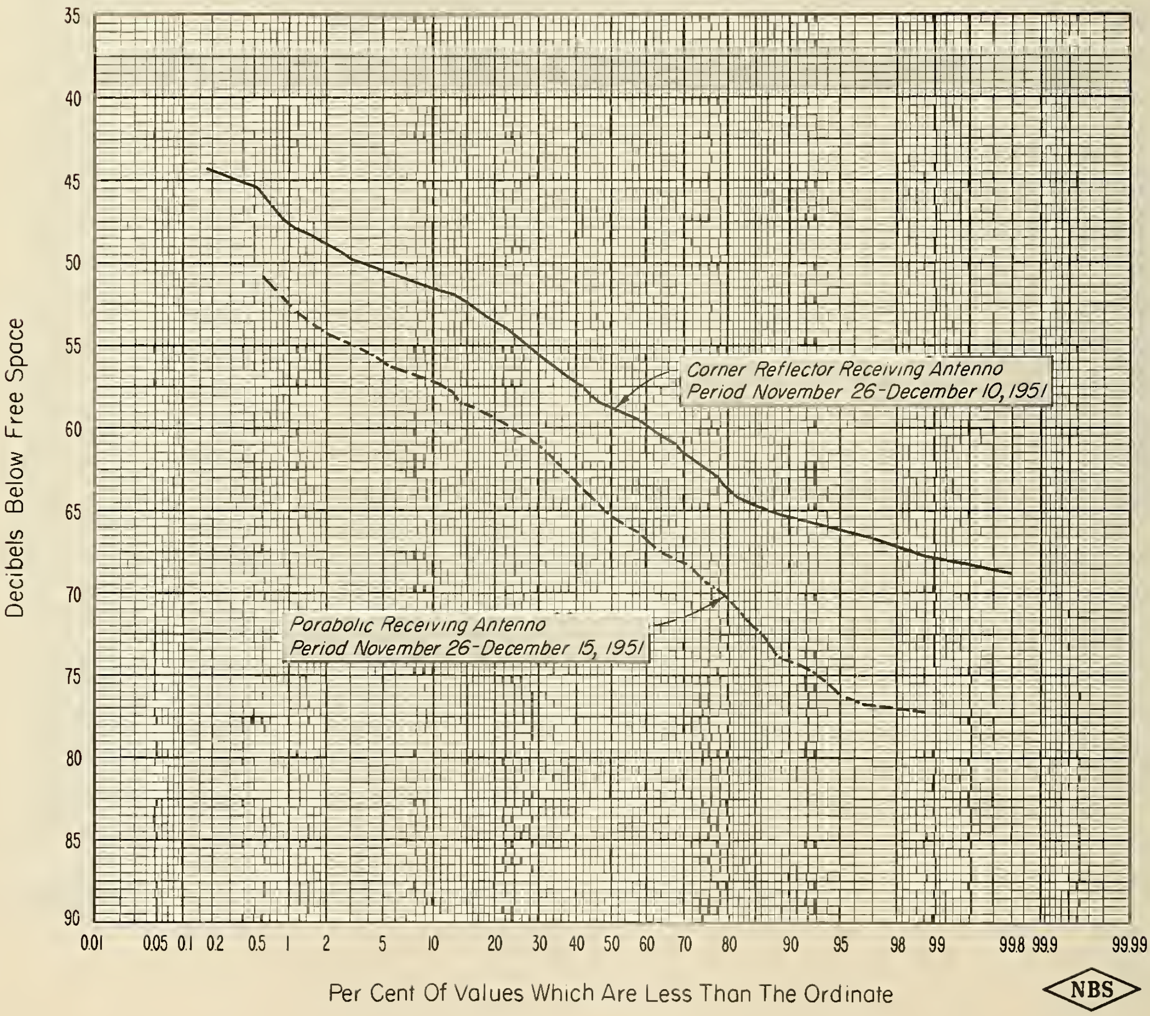


Figure 32

DISTRIBUTION OF ALL HOURLY MEDIAN SIGNAL LEVELS
RECORDED DURING PERIOD APRIL 30 - DECEMBER 15, 1951

418 Mc Cedar Rapids, Iowa - Quincy, Illinois Measurements

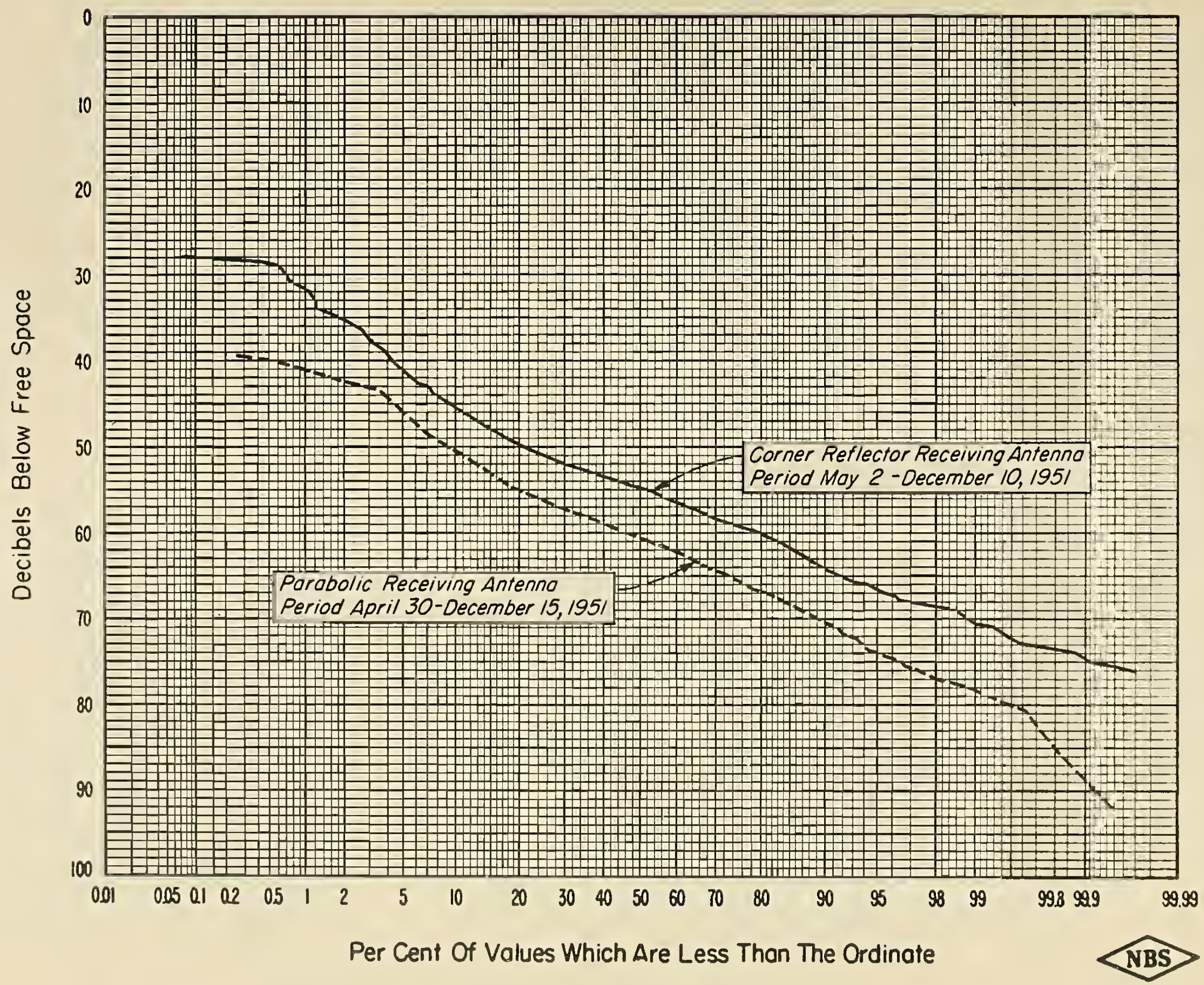


Figure 33

DIURNAL VARIATION OF LEVELS EXCEEDED
BY 10%, 50% AND 90% OF HOURLY MEDIANS

418 Mc CEDAR RAPIDS - QUINCY MEASUREMENTS
PARABOLIC RECEIVING ANTENNA

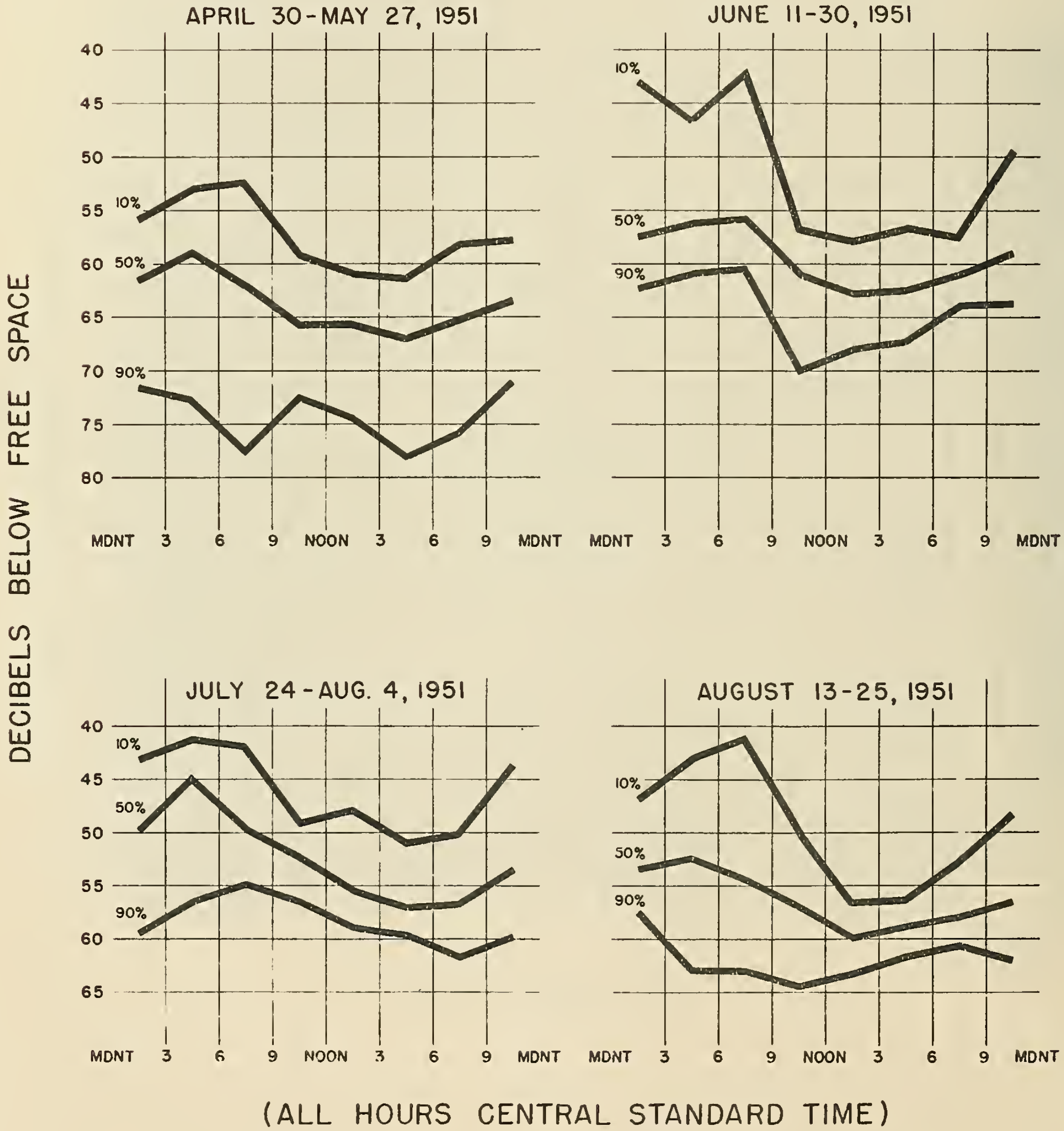


Figure 34

DIURNAL VARIATION OF LEVELS EXCEEDED BY 10%, 50% AND 90% OF HOURLY MEDIANS

418 Mc CEDAR RAPIDS - QUINCY MEASUREMENTS
PARABOLIC RECEIVING ANTENNA

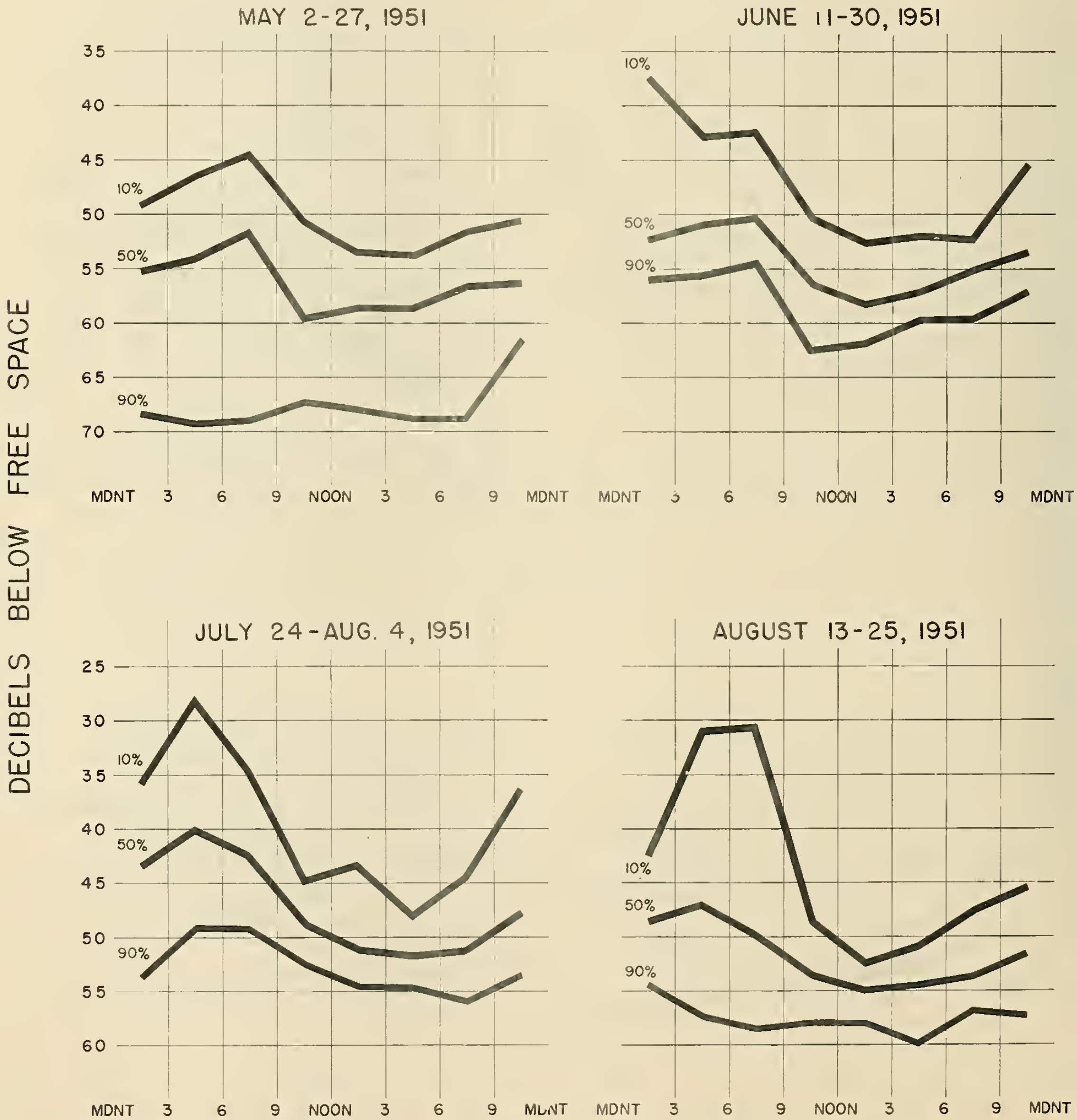
(ALL HOURS CENTRAL STANDARD TIME)

Figure 35

NBS

DIURNAL VARIATION OF LEVELS EXCEEDED BY 10%, 50% AND 90% OF HOURLY MEDIANS

418 Mc CEDAR RAPIDS - QUINCY MEASUREMENTS
CORNER REFLECTOR RECEIVING ANTENNA



(ALL HOURS CENTRAL STANDARD TIME)

NBS

Figure 36

DIURNAL VARIATION OF LEVELS EXCEEDED BY 10%, 50% AND 90% OF HOURLY MEDIANS

418 Mc CEDAR RAPIDS - QUINCY MEASUREMENTS
CORNER REFLECTOR RECEIVING ANTENNA

(ALL HOURS CENTRAL STANDARD TIME)

Figure 37

NBS

VARIABILITY OF HOURLY MEDIAN SIGNAL LEVELS

Difference Between Levels Exceeded by 10% and 90% of Medians

Cedar Rapids - Quincy Path; 418 Mc; 1951

Figure 38

NBS

MONTH TO MONTH VARIATION OF EARLY MORNING AND MID-AFTERNOON MEDIAN SIGNALS

418 Mc CEDAR RAPIDS-QUINCY MEASUREMENTS *PARABOLIC RECEIVING ANTENNA*

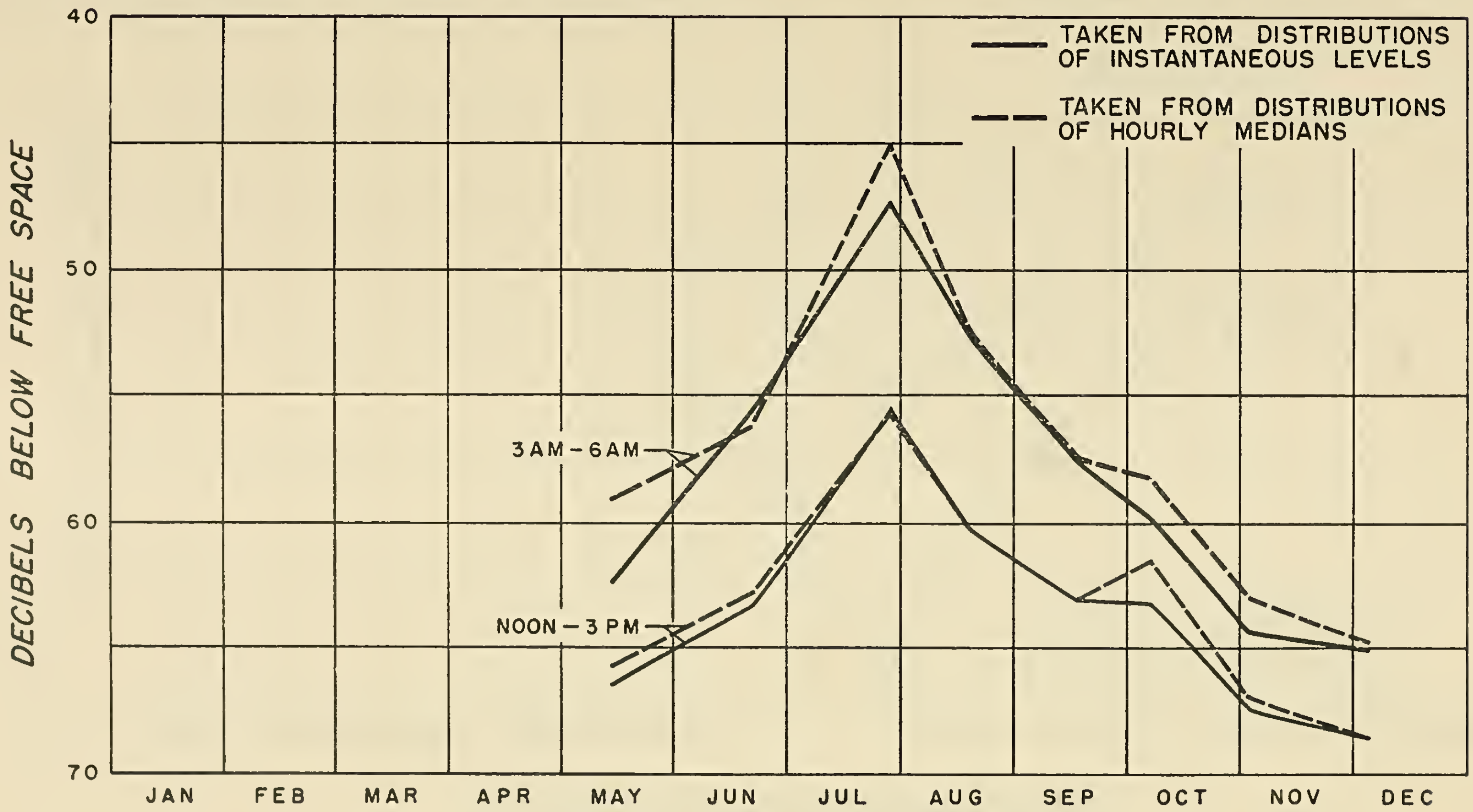


Figure 39

NBS

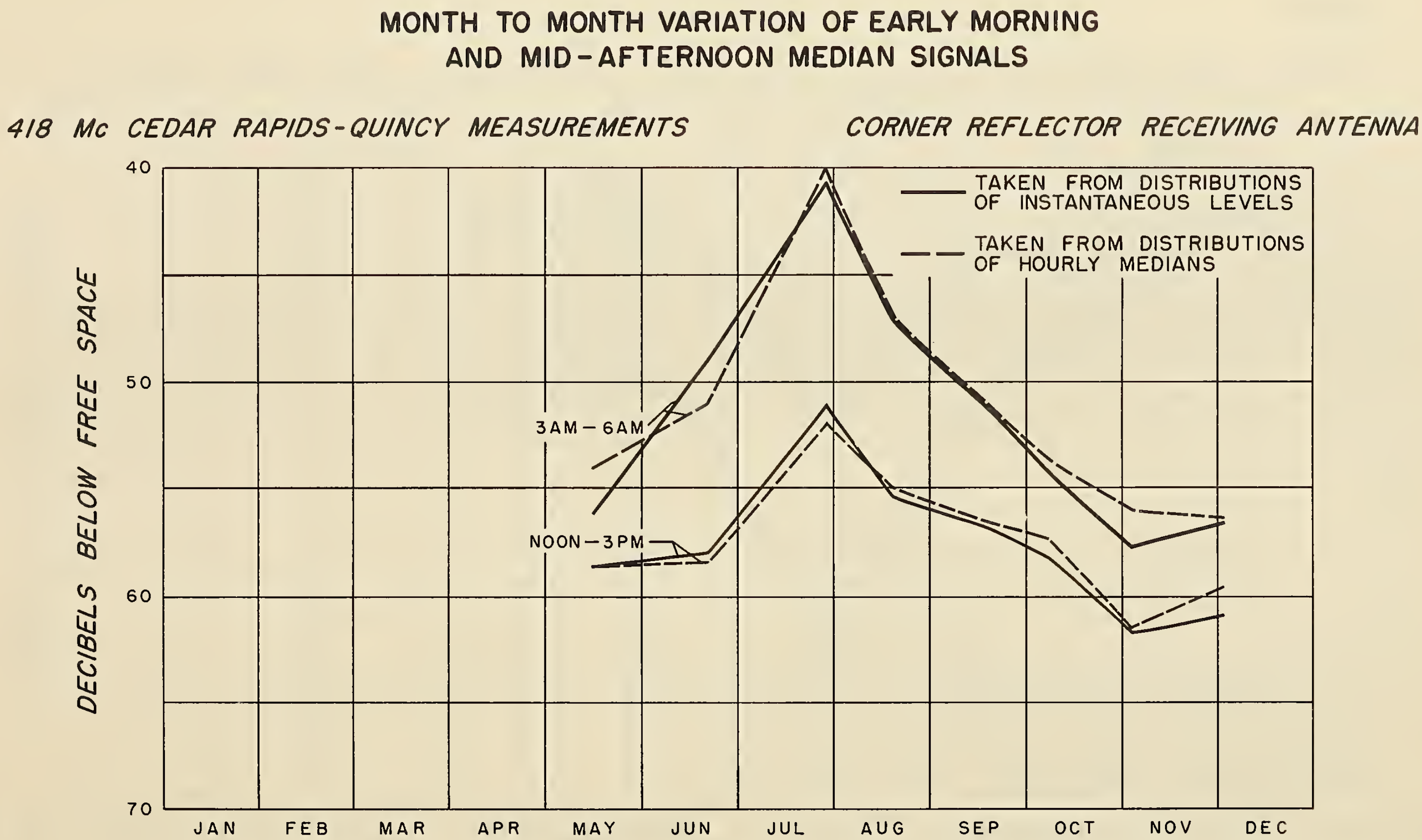

MONTH TO MONTH VARIATION OF EARLY MORNING
AND MID-AFTERNOON MEDIAN SIGNALS
418 Mc CEDAR RAPIDS-QUINCY MEASUREMENTS
CORNER REFLECTOR RECEIVING ANTENNA
DECIBELS BELOW FREE SPACE
40
50
60
70
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
TAKEN FROM DISTRIBUTIONS OF INSTANTANEOUS LEVELS
TAKEN FROM DISTRIBUTIONS OF HOURLY MEDIANS
3AM — 6AM
NOON — 3PM

Figure 40

MONTH TO MONTH VARIATION OF LEVELS EXCEEDED BY 10%, 50% AND 90% OF HOULY MEDIANS

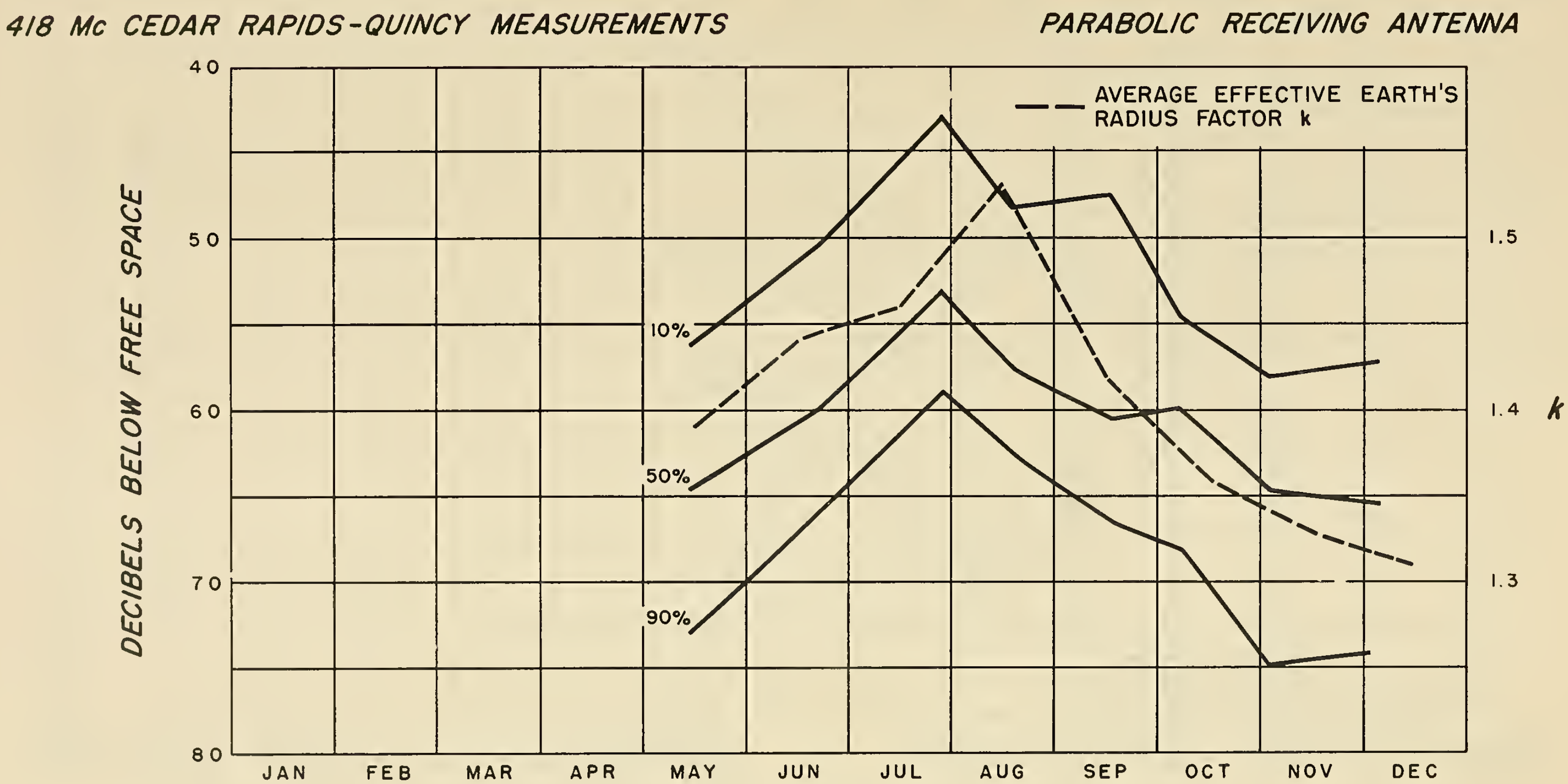


Figure 41

NBS

MONTH TO MONTH VARIATION OF LEVELS EXCEEDED BY 10%, 50% AND 90% OF HOULY MEDIANS

418 Mc CEDAR RAPIDS-QUINCY MEASUREMENTS *CORNER REFLECTOR RECEIVING ANTENNA*

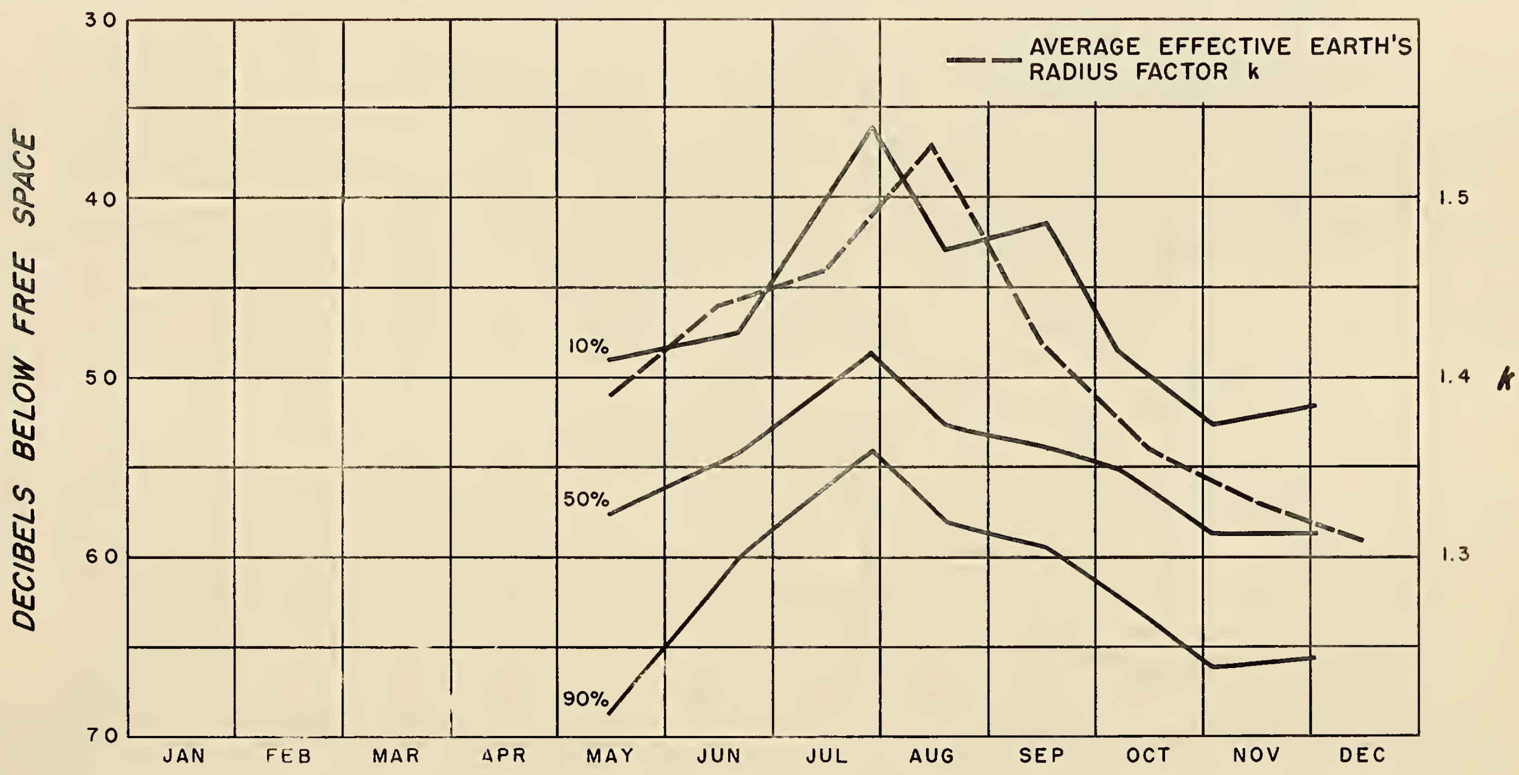


Figure 42

MONTH TO MONTH VARIATION IN EFFECTIVE GAIN
OF PARABOLA RELATIVE TO CORNER REFLECTOR

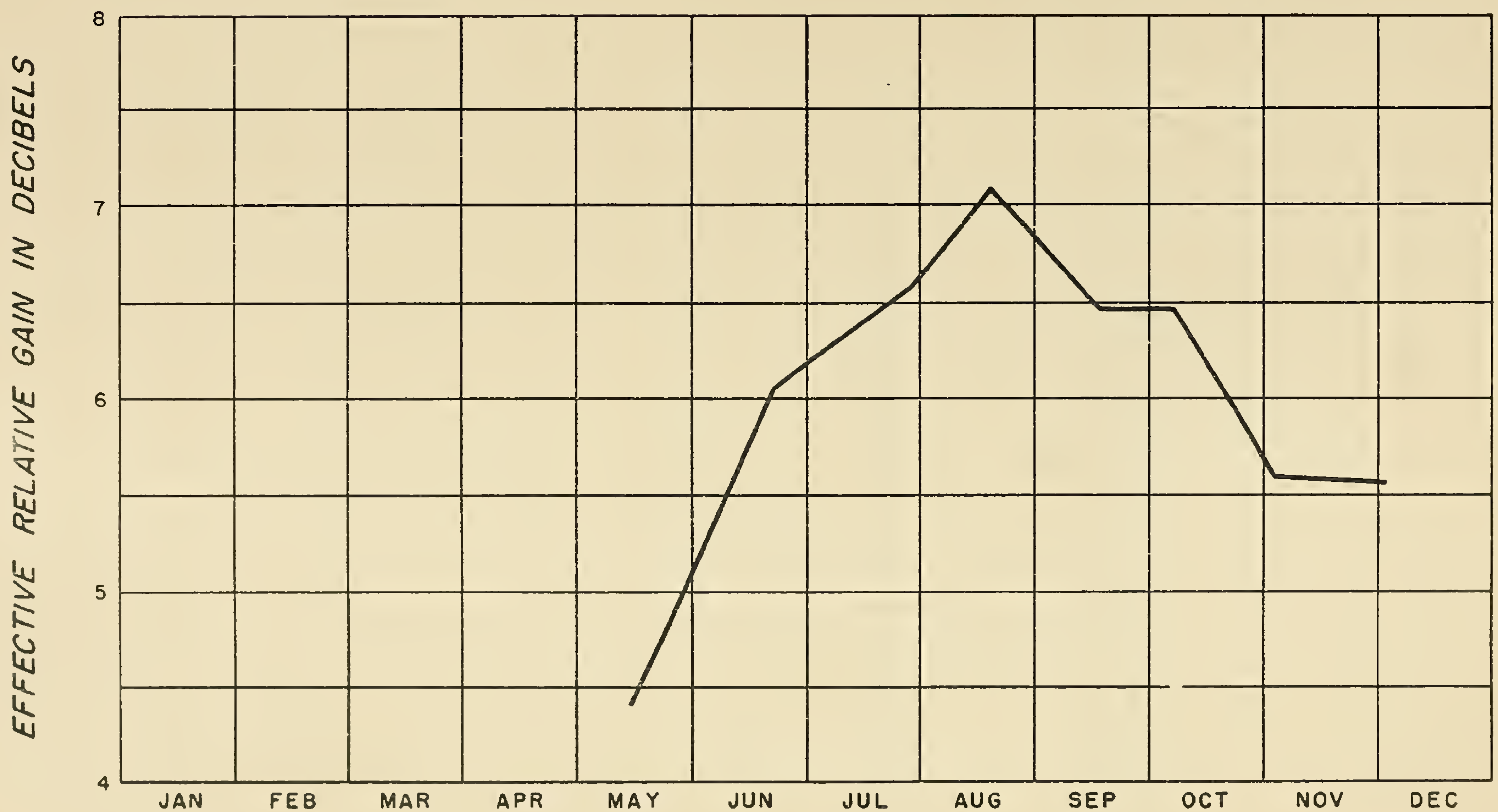


Figure 43

NBS

Supplement IV

PRELIMINARY REPORT ON PROPAGATION MEASUREMENTS FROM 92 - 1046 Mc AT CHEYENNE MOUNTAIN, COLORADO

By

G. R. Chambers, J. W. Herbstreit, and K. A. Norton

Supplement IV

PRELIMINARY REPORT ON PROPAGATION MEASUREMENTS FROM 92-1046 Mc AT CHEYENNE MOUNTAIN, COLORADO

By

G. R. Chambers, J. W. Herbstreit, and K. A. Norton
National Bureau of Standards
Boulder, Colorado

SUMMARY

A description is given of the facilities provided by the National Bureau of Standards on Cheyenne Mountain in Colorado and in its vicinity which are used for the measurement of the transmission loss on radio transmission circuits operated in the frequency range from 92 to 1046 Mc. Some preliminary results of these measurements are presented together with tentative theoretical explanations.

INTRODUCTION

The National Bureau of Standards Cheyenne Mountain Field Station at Colorado Springs, Colorado, has been established to supply radio propagation information which closely approximates transmissions from an aircraft to distances far beyond the horizon. Information is being obtained in such a way that results advance our over-all knowledge of the factors influencing radio propagation in other parts of the world and in other radio systems not immediately under study.

At the close of World War II, considerable effort was being made in the air navigation field to develop a unified system of air communications and navigation in the frequency range 960 to 1600 Mc. This work is now centralized in the Air Navigation and Development Board which is administratively under the Civil Aeronautics Administration.

Very little quantitative information exists relative to the effects of irregular terrain for transmission paths within the radio line-of-sight and still less at distances beyond the usual service range of navigational systems where signals would be a source of interference to nearby facilities operating on the same or adjacent frequency channels.

In order to expedite the program of research in tropospheric propagation which is designed to determine propagation factors required for effective allocation and use of VHF and UHF frequency bands, particularly from an air navigation standpoint, the Air Navigation and Development Board has been sponsoring a rapid expansion of the tropospheric propagation research facilities of the National Bureau of Standards at Cheyenne Mountain, including the development, installation and operation of a system for studying propagation factors at approximately 1000 Mc. This system utilizes a transmitter which gives the highest continuous power output of any 1000 Mc transmitter ever developed in this country and specially developed very narrow bandwidth receivers capable of measuring received signal powers much lower than usual receivers for this frequency range. This high level of system performance is necessary to obtain radio propagation data at great distances.

The United States Army Signal Corps, because of their vital need for radio propagation information in the VHF and UHF frequency bands, have also been sponsoring the acceleration and expansion of research facilities at Cheyenne Mountain. Military personnel of the Signal Corps are participating in the work and are receiving training in the methods of making VHF and UHF radio propagation measurements.

The Cheyenne Mountain measurements at frequencies between 92 and 210.4 Mc, which are not in the proposed air-navigation band, provide a means of studying climatic effects on tropospheric propagation in Colorado and vicinity, for comparison with many other regions of the country where measurements have been made at these presently-used air-navigation communications, FM and television frequencies. A high system performance in the range 92-210.4 Mc has been achieved through the use of stabilized transmitters, relatively high antenna gains and very narrow-band receivers.

A picture of the over-all VHF-UHF tropospheric field strength program of the National Bureau of Standards may be obtained from Fig. 1. This shows the numerous propagation paths over which VHF and UHF field strengths are being measured.

SYSTEM SELECTION

When the National Bureau of Standards was requested to accelerate its tropospheric propagation research program, a complete study of existing facilities and equipment was initiated. System design, selection of a suitable site, and establishment of the Cheyenne Mountain Field Station followed. Some of the most important factors concerned with the selection of the Cheyenne Mountain location and system design employed are as follows:

A. Site

It was proposed to locate a site and install a system for long term continuous radio-propagation measurements over air-to-ground paths near and below the horizon. Use of aircraft for one terminal was considered prohibitively expensive and impractical for long-term continuous recording; moreover, their use would not permit the obtaining of data under extremes of weather conditions. For these reasons, ground installations which would simulate an air-to-ground path were sought. Accordingly, after an extensive survey, a site on Cheyenne Mountain near Colorado Springs, Colorado, was chosen. This mountain, 9200 feet above sea level, rises abruptly out of the eastern Colorado plains and provides an excellent "airborne terminal" which is over 3000 feet above the adjacent plains. The existing all-weather road and high-voltage power facilities to the mountain summit were also important factors to be considered. Receiving sites and paths with almost any desired characteristics were available at the distances of interest, including smooth, moderately rough and rough terrain, as well as some of the most rugged terrain in North America. In addition, highway systems extending eastward into Colorado, Kansas, and Arkansas, offered a number of approximately radial all-weather highways, suitable for mobile recordings and convenient to fixed recording sites. The location of the Army's Camp Carson and the Air Force installation at Peterson Field in Colorado Springs were considered as making future aircraft investigations and measurements practical.

B. Equipment

The preliminary objectives of the Cheyenne Mountain experiments are to measure radio field strength produced near and far beyond the radio horizon with a carefully monitored transmission and recording system which is divided into four equipment classes: (a) Transmitting, (b) Receiving, (c) Recording, and (d) Calibrating. These are described generally as follows:

(a) Transmitting - The operating frequencies are 92, 100, 192.8, 210.4 and 1046.4748 Mc. The available continuous power output is 3 kw at 92 and 100 Mc and 4 kw at 192.8, 210.4 and 1046.4748 Mc. During propagation measurements the transmitted energy at each frequency is confined to a band less than 50 cycles wide. This in combination with narrow-band receivers insures the maximum "Margin of Detectability" for a given receiver and provides data at maximum distances. As pointed out in the description of system selection, the detectable signal in a given system is essentially a function of average power output, bandwidths, and threshold-detection factors. Reducing the receiver bandwidths or detection factors by 1/2 is effectively the same as increasing the average transmitter power output by a factor of two. As an example, if received signal power at some given distance were recorded on a regular commercial FM operation at 100 Mc where the receiver bandwidth is necessarily 150 kc and the effective radiated power of the transmitter 10 kw, the equivalent power for field-strength recording purposes could effectively be increased to 3000 kw by reducing the transmitter drift and incidental modulation to much less than 500 cycles and the effective noise bandwidth of the receiver to 500 cycles.

The frequency stability of each transmitter is capable of being maintained within ± 200 cycles of the assigned carrier frequency. This insures that the transmitted signal power is measured within the ± 1/2 db flat-top response of the receivers. The frequency-monitoring equipment for checking the transmitter frequencies utilizes a Hewlett-Packard frequency counter in conjunction with a General Radio Primary Frequency Standard.

All transmitting antennas have moderate power gains. Since the purpose of these studies was to observe propagation over air-to-ground paths under conditions similar to those of typical air-navigation systems, omni-directional transmitting and receiving antennas would have been most desirable. However, a mountain is not a typical airborne terminal because of other mountains to the rear and at either side. These mountains are excited by the RF fields of the transmitting antennas and reradiation occurs. In order to minimize this reradiation from the adjacent terrain and to approach the conditions expected for a typical air-navigation system some moderate directivity is desirable. A careful survey of the transmitting sites resulted in a choice of an over-all solid angle of radiation corresponding to ranges of 60 degrees in azimuth and 15 degrees in elevation. Fig. 8 is a photograph of the transmitting antennas at the summit site. The VHF antennas at the base site are identical.

Modulation systems were provided in all transmitters to assist in carrier identification and to provide facilities for modulation studies.

(b) Receiving - The receiving equipment was designed to measure accurately the transmission loss on each of the five frequencies involved. It has several features to improve its stability characteristics and make it adaptable to a narrow-band recording system. General recording characteristics of all receivers are approximately the same, but the design and construction features of the VHF and UHF equipment differ widely because of frequency.

Both the VHF and UHF receiving equipment are frequency stabilized by multiplying the 100 kc output of a primary frequency standard to the appropriate oscillator injection-voltage frequencies. In locations where recordings are made on all frequencies, one common primary frequency standard is used for five receivers. The receiver circuits for feeding the data-recording equipment are essentially the same for all receivers. The equipment installation and facilities in the mobile recording units are the same as those at the fixed recording sites.

(c) Recording - Received power is recorded at all locations on clock-driven charts, and at the more distant recording sites, where fading makes analysis of chart data impractical, on time-totalizing recorders. These time-totalizing recorders are equivalent to a battery of clocks, each one recording the total time that a certain pre-set signal level is exceeded. Each clock is activated by the receiver when the appropriate pre-set signal level is crossed. Readings of the clocks are periodically recorded by an automatic camera system.

(d) Calibrating - The calibration of receivers and measurement of the available signal power from the system is based on a comparison between that available from the receiving antenna transmission line and that available from the output of a calibrated signal generator with the same impedance (50 ohms). All signal generators used at various locations are related to a standard and to transmitter power indication devices.

SYSTEM OPERATION

Propagation data at Cheyenne Mountain are collected on a continuous twenty-four-hour-per-day basis. This schedule is limited only by loss of time due to regular maintenance or equipment failures. Less than 60 per cent of this goal has been realized to date because of slow equipment deliveries, new equipment faults, and problems of perfecting system operation, and the training of operating personnel.

As of March, 1952, however, all transmitters were operating on a continuous schedule. The fixed sites at distances of 49.3, 70.2, 96.6, and 226.5 miles are visited and calibrated at least once each day. The mobile sites have been operated for relatively limited periods at several locations. It is not planned to make continuous measurements at long distances but to take periodic samples of data during typical seasonal climatological conditions. Some special recordings planned for the near future include samples of data at distances equivalent to the fixed sites over several dissimilar paths and recordings at many additional locations over line-of-sight paths.

SYSTEM RESULTS

Field-strength recordings have been made on all frequencies at various distances from the transmitters. Recordable signals have been received on 92, 100, 192.8 and 1046 Mc as far as Anthony, Kansas, a distance of 393.5 miles, and on 100 Mc at Fayetteville, Arkansas, a distance of 616.3 miles. Recordings are now being made at each of the four fixed receiving sites shown in Fig. 2 on a regular basis in order to obtain measurements over an extended period of time for the purpose of studying the effects of diurnal and seasonal factors on the transmission loss (received field strength) as a function of distance, frequency, and antenna heights.

REFERENCES

1/ K. A. Norton and A. C. Omberg, "Maximum Range of Radar Set," Proc. IRE, 35, January 1947, pp. 4-28.

2/ J. L. Lawson and G. E. Uhlenbeck, "Threshold Signals," Vol. 24, MIT Radiation Laboratory Series, McGraw Hill Publishing Company.

3/ K. A. Norton, "Transmission Loss in Radio Propagation," report in preparation at the National Bureau of Standards.

4/ Federal Communications Commission Engineering Department. Report on Very High Frequency Field Strength Measurements 1943-1944; Hearing in the Matter of the Allocation of Radio Frequencies Between 10 kc and 30,000 Mc, September 28, 1944, Docket 6651. See also E. W. Allen, "Very-High-Frequency and Ultra-High-Frequency Signal Ranges as Limited by Noise and Co-Channel Interference," Proc. IRE, 35, February 1947, pp. 128-152.

5/ J. Feinstein, "The Interpretation of Radar Echoes From Meteor Trails," Journal of Geophysical Research, 56, March 1951.

6/ A. C. B. Lovell, J. P. M. Prentice, J. G. Porter, R. W. B. Pearse, N. Herlofson, "Meteors, Comets and Meteoric Ionization," Physical Society, London, Reports on Progress in Physics, Vol. XI, pp. 389-454, 1948.

7/ Federal Communications Commission Ad Hoc Committee For the Evaluation of the Propagation Factors Concerning Television and Frequency Modulation Broadcasting; Services in the Frequency Range Between 50 and 250 Mc, Vol. I, May 31, 1949.

8/ H. Fine and F. V. Higgins, "Long Distance Tropospheric Propagation in the Ultra High Frequency Band," Federal Communications Commission Report TRR 2.4.10, October 13, 1950.

9/ J. Feinstein, "Tropospheric Propagation Beyond the Horizon," Journal of Applied Physics, 22, October 1951, pp. 1292-1293.

10/ B. Ratner, "Upper Air Average Values of Temperature, Pressure, and Relative Humidity Over the United States and Alaska," U. S. Dept. of Commerce, Weather Bureau, Climate and Crop Weather Division, Washington, D. C., May 1945.

11/ K. A. Norton, "Physical Reality of Space and Surface Waves in the Radiation Field of Radio Antennas," Proc. IRE, 25, pp. 1192-1202, September 1937.

12/ K. A. Norton, "Calculation of Ground Wave Field Intensity Over a Finitely Conducting Spherical Earth," Proc. IRE, 29, pp. 623-639, December 1941.

13/ H. J. Riblet and C. B. Barker, "A General Divergence Formula," Journal of Applied Physics, 19, pp. 63-70, January 1948.

14/ B. R. Bean, "Geographical and Height Distribution of the Gradient of Refractive Index," National Bureau of Standards report in preparation.

15/ K. A. Norton, "Propagation in the FM Broadcast Band," Advances in Electronics, Vol. I, pp. 406-408, Academic Press, Inc., New York, 1948.

16/ K. A. Norton, M. Schulkin, and R. S. Kirby, "Ground-Wave Propagation Over Irregular Terrain at Frequencies Above 50 Mc," Reference C to the Report of the Ad Hoc Committee of the Federal Communications Commission for the Evaluation of the Propagation Factors Concerning the Television and Frequency Modulation Broadcasting Services in the Frequency Range Between 50 and 250 Mc, June 8, 1949.

17/ J. C. Schelleng, C. R. Burrows and E. B. Ferrell, "Ultra-Short-Wave Propagation," Proc. IRE, 21, March 1933, pp. 427-463.

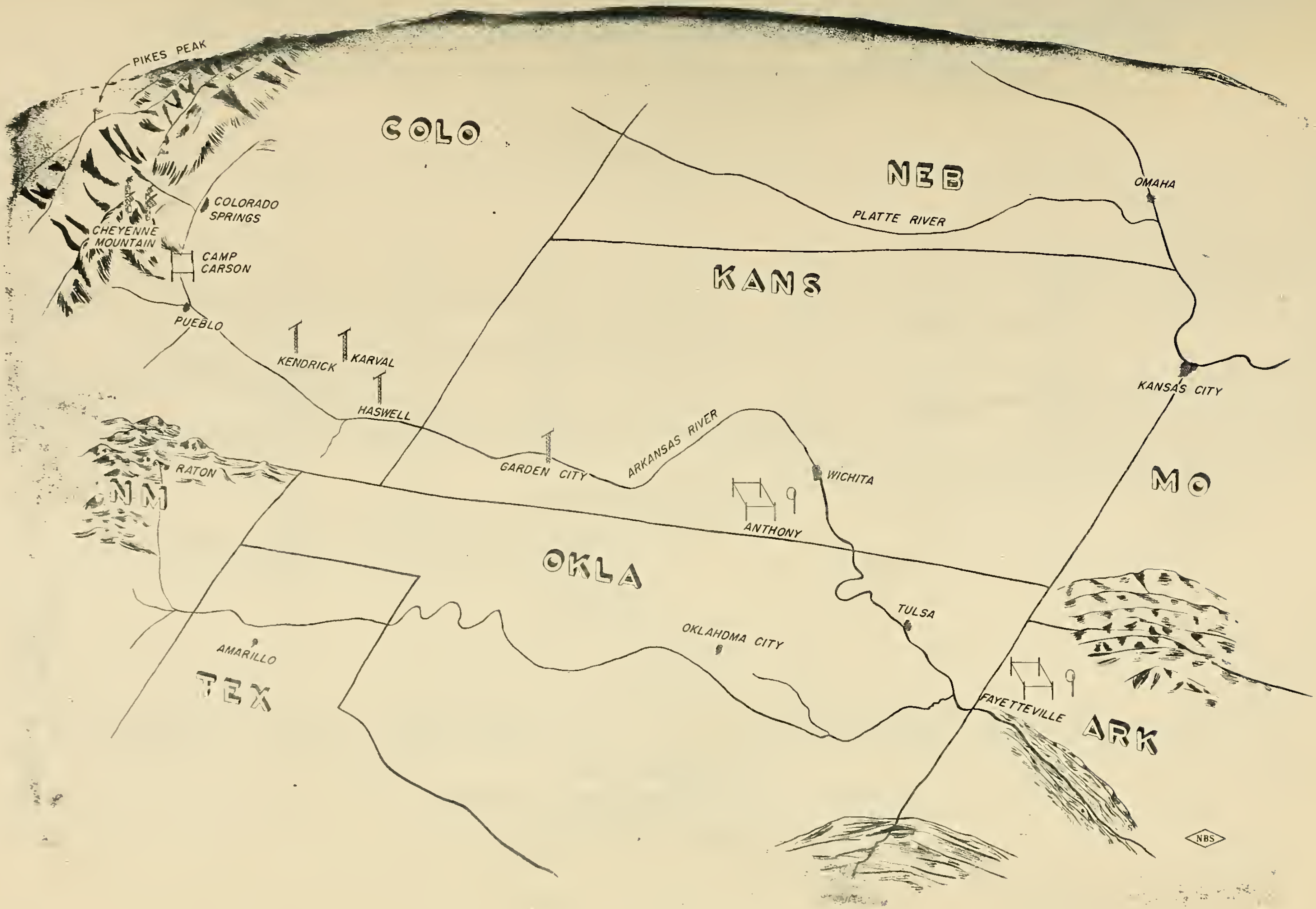
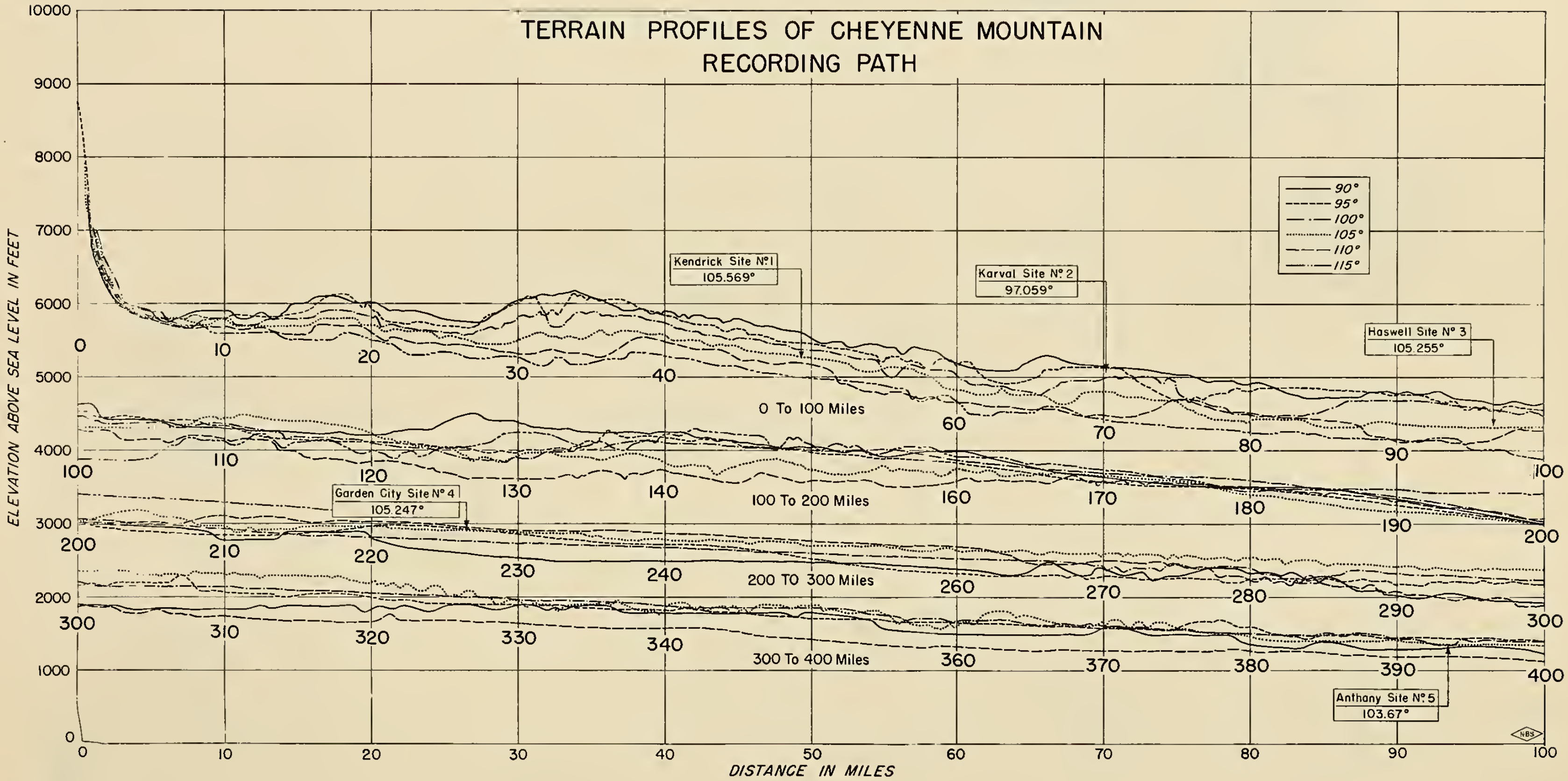

PIKES PEAK
COLO
NEB
OMAHA
PLATTE RIVER
COLORADO SPRINGS
CHEYENNE MOUNTAIN
CAMP CARSON
KANS
PUEBLO
KENDRICK
KARVAL
HASWELL
KANSAS CITY
ARKANSAS RIVER
GARDEN CITY
WICHITA
RATON
NM
MO
ANTHONY
OKLA
TULSA
OKLAHOMA CITY
AMARILLO
TEX
FAYETTEVILLE
ARK
NBS

FIG. I

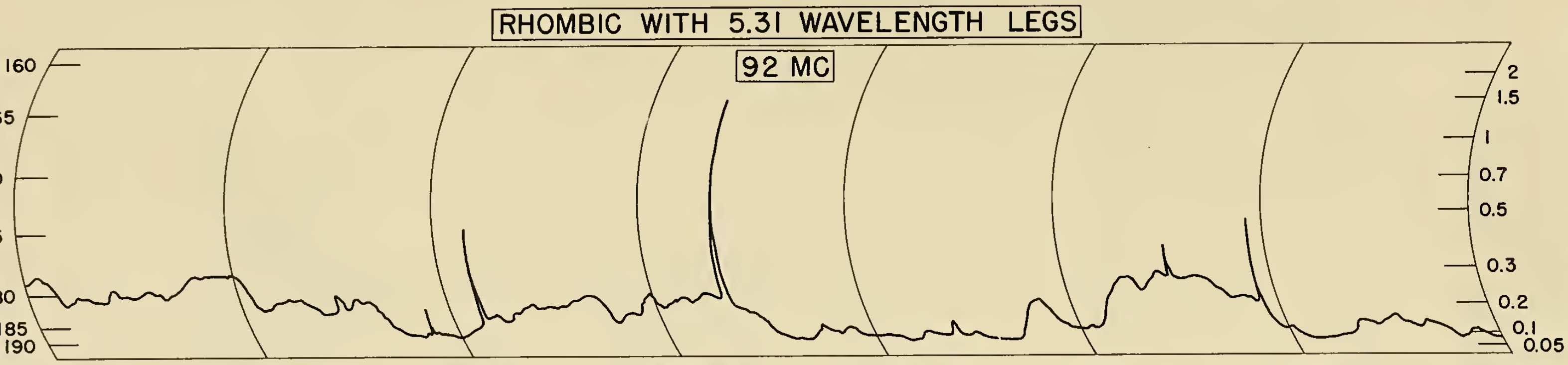


TERRAIN PROFILES OF CHEYENNE MOUNTAIN
RECORDING PATH
ELEVATION ABOVE SEA LEVEL IN FEET
DISTANCE IN MILES
90°
95°
100°
105°
110°
115°
Kendrick Site No 1
105.569°
Karval Site No 2
97.059°
Haswell Site No 3
105.255°
Garden City Site No 4
105.247°
Anthany Site No 5
103.67°
0 To 100 Miles
100 To 200 Miles
200 TO 300 Miles
300 To 400 Miles
NBS

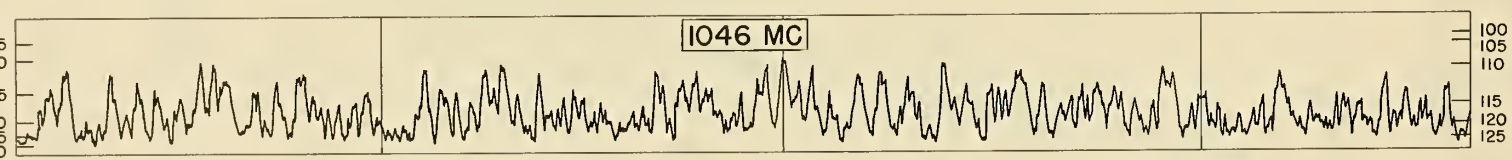
Figure 6

SAMPLE FAST SPEED RECORDINGS OF 92 MC AND 1046 MC TRANSMISSIONS FROM CHEYENNE MOUNTAIN

Distance 393.5 Miles



February 20, 1952



February 12, 1952

Figure 21

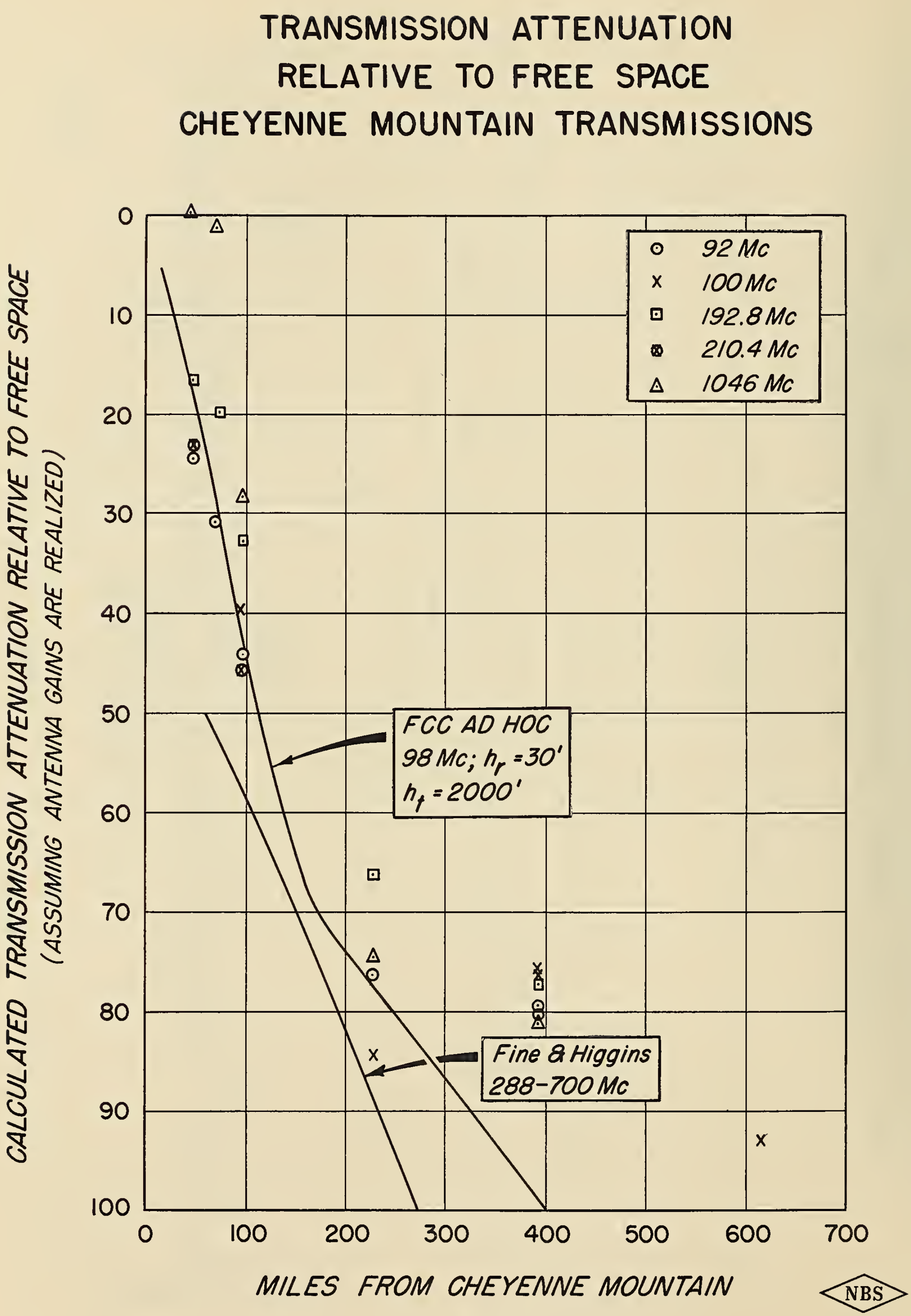
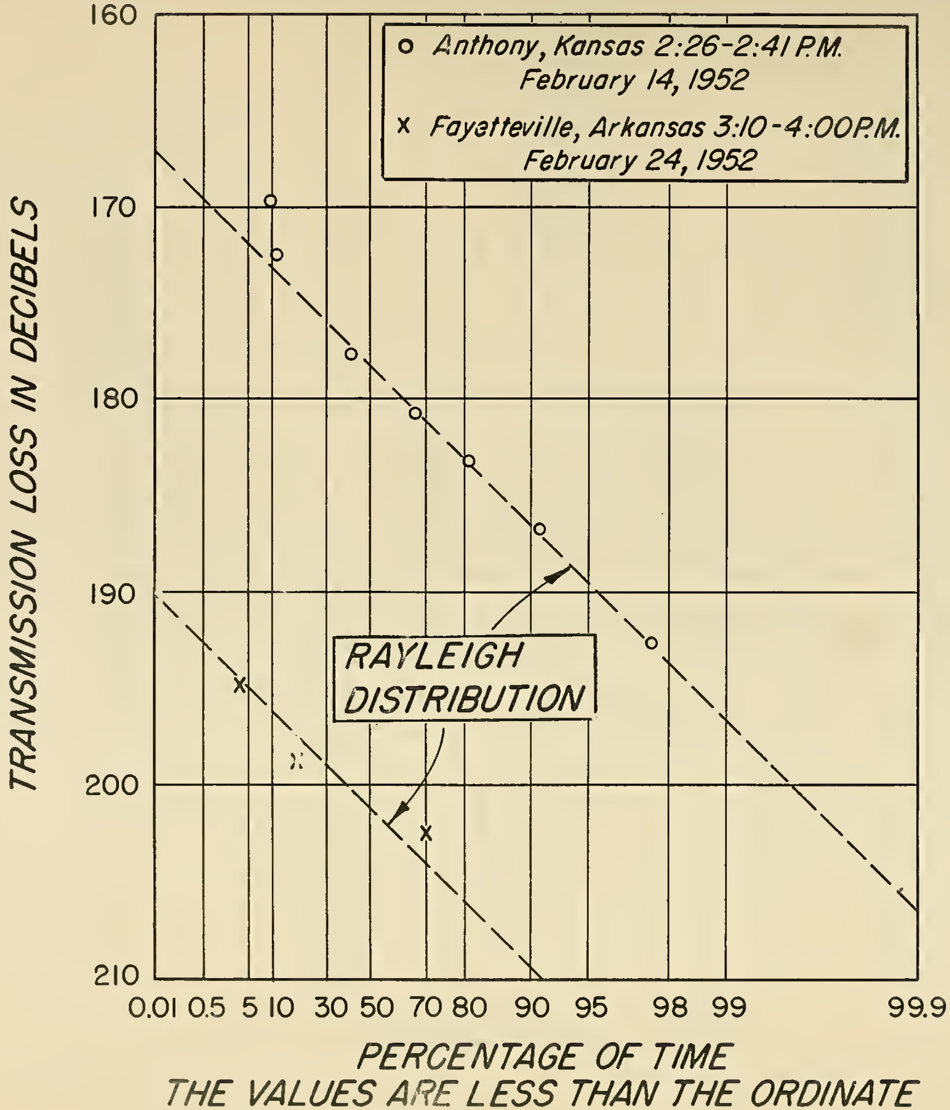

TRANSMISSION ATTENUATION
RELATIVE TO FREE SPACE
CHEYENNE MOUNTAIN TRANSMISSIONS
CALCULATED TRANSMISSION ATTENUATION RELATIVE TO FREE SPACE
(ASSUMING ANTENNA GAINS ARE REALIZED)
0
10
20
30
40
50
60
70
80
90
100
92 Mc
100 Mc
192.8 Mc
210.4 Mc
1046 Mc
FCC AD HOC
98 Mc; h_r = 30'
h_t = 2000'
Fine & Higgins
288-700 Mc
0
100
200
300
400
500
600
700
MILES FROM CHEYENNE MOUNTAIN
NBS

Figure 24

DISTRIBUTIONS OF INSTANTANEOUS SIGNAL LEVELS RECEIVED ON 100 MC AT 393.5 AND 616.3 MILES

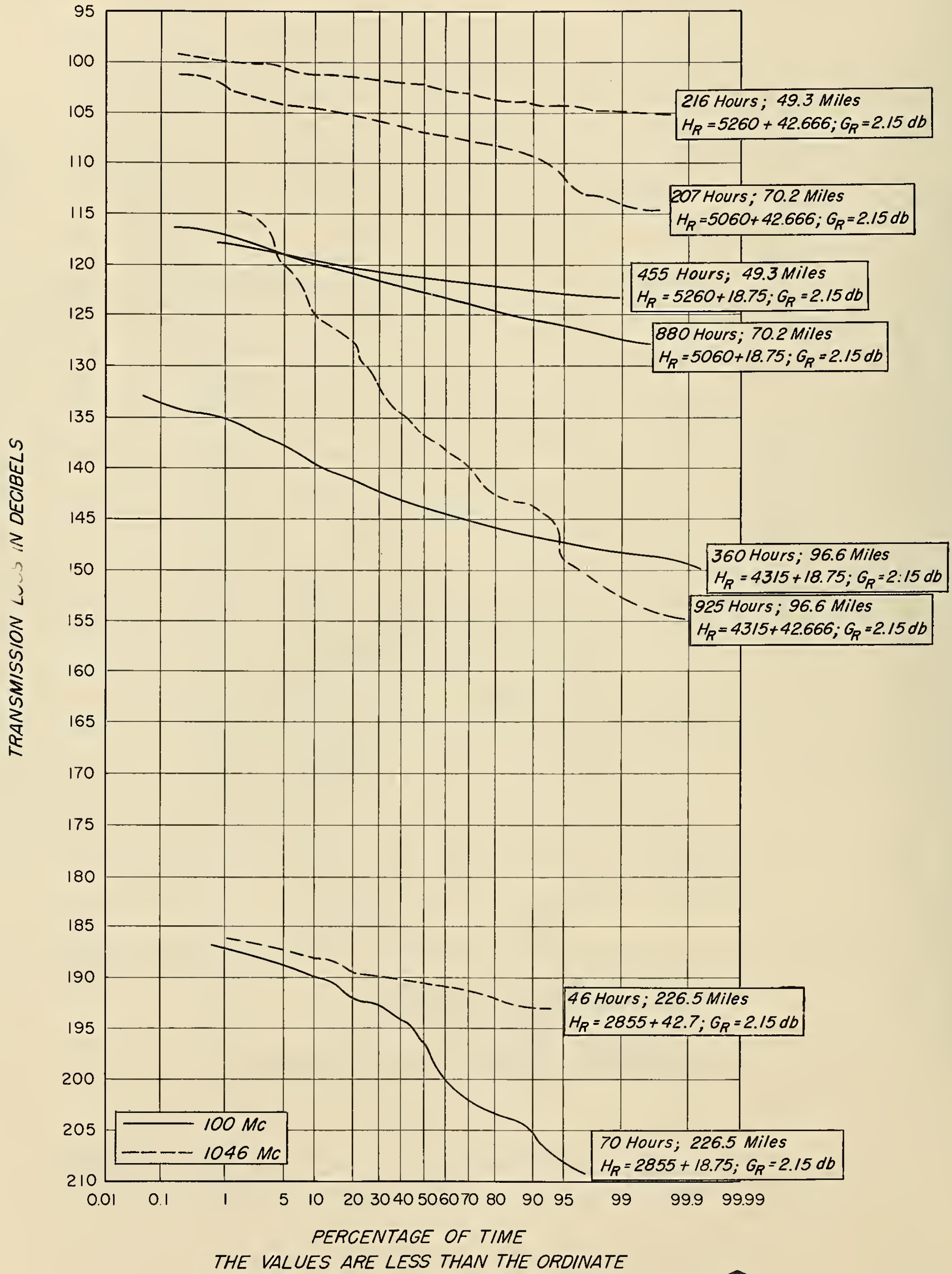


NBS

Figure 28

DISTRIBUTIONS OF HOURLY MEDIAN SIGNAL LEVELS
RECEIVED BETWEEN JANUARY 20 AND APRIL 1, 1952

100 Mc Transmitting Antenna $H_t = 5805 + 3000$ Feet; $G_t = 9.98$ db
1046 Mc Transmitting Antenna $H_t = 5805 + 2955$ Feet; $G_t = 26$ db

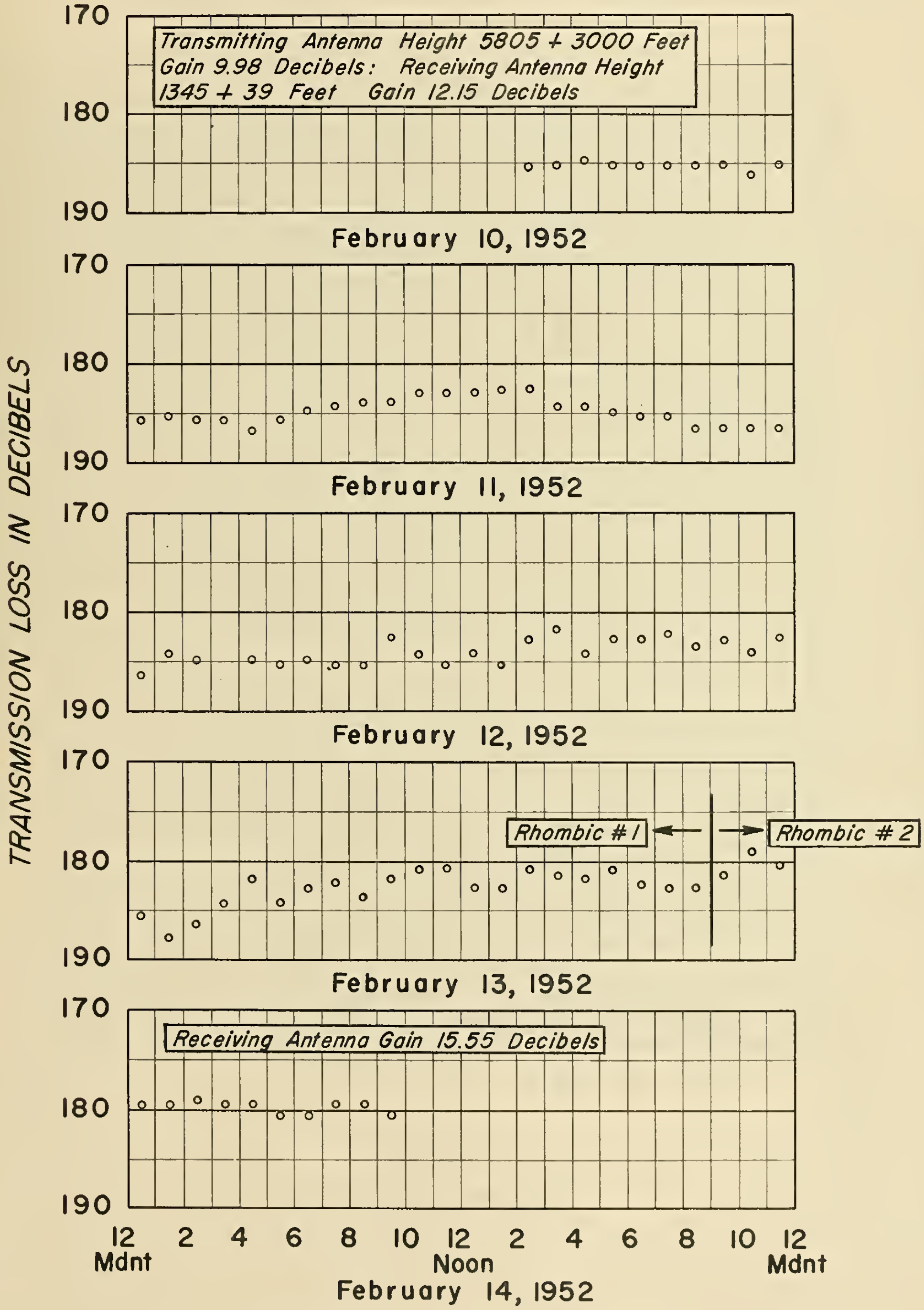


NBS

Figure 29

DIURNAL VARIATION OF HOURLY MEDIAN FIELDS RECEIVED ON 100 MC AT ANTHONY, KANSAS

Distance 393.5 Miles



NBS

Figure 32

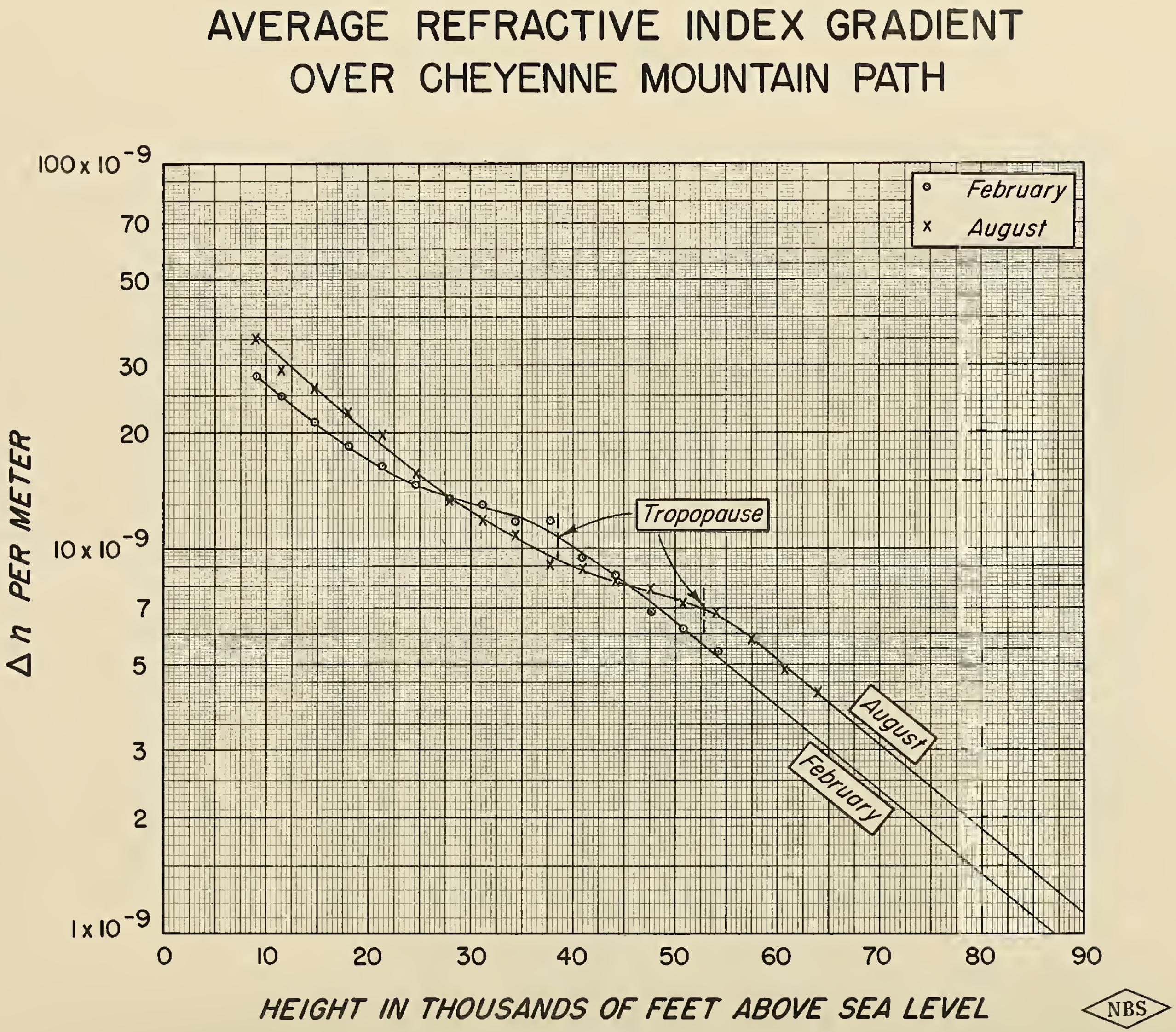

AVERAGE REFRACTIVE INDEX GRADIENT
OVER CHEYENNE MOUNTAIN PATH
100 x 10⁻⁹
70
50
30
20
10 x 10⁻⁹
7
5
3
2
1 x 10⁻⁹
Δ n PER METER
0
10
20
30
40
50
60
70
80
90
HEIGHT IN THOUSANDS OF FEET ABOVE SEA LEVEL
February
August
Tropopause
August
February
NBS

Figure 34

Supplement V

TROPOSPHERIC PROPAGATION MEASUREMENTS WITHIN THE RADIO HORIZON OVER CHEYENNE MOUNTAIN PATHS

By

A. P. Barsis

Supplement V

TROPOSPHERIC PROPAGATION MEASUREMENTS WITHIN THE RADIO HORIZON OVER CHEYENNE MOUNTAIN PATHS

By

Albrecht P. Barsis
National Bureau of Standards
Boulder, Colorado

SUMMARY

The tropospheric propagation measurements being conducted by the Cheyenne Mountain Field Station of the Central Radio Propagation Laboratory include several optical paths, over which continuous recordings of field intensity are made on 100 Mc, 192.8 Mc and 1046 Mc. Measurements at two fixed receiving sites located on a path running 105^{o} east of true north from the transmitter site on Cheyenne Mountain are analyzed and the results of 12 months of continuous recordings are presented in the form of charts showing diurnal and month-to-month variations of hourly median values of received field.

In order to determine diurnal variations, values of hourly medians for each month are grouped into eight three-hour periods, and monthly distributions of hourly medians are determined for each of these periods, as well as overall monthly distributions combining all diurnal periods for each frequency at each site. The difference (in decibels) of hourly medians exceeding 10% and 90% of the total numbers of hours for each recording period may be termed the interdecile range of the received hourly median, and its dependence on the overall median level, time of day, and its change from month to month is investigated for each site and each frequency.

The 1046 Mc signal shows occasional fades amounting to 5 to 15 db and lasting from 20 minutes to several hours. A comparison is made of the behavior of the signal on the lower frequencies during the times these fades occur. Examination of the frequency of occurrence of these "prolonged space-wave fadeouts" shows that they are substantially more prevalent in summer than in winter, and that they occur principally at night.

1. INTRODUCTION

The Cheyenne Mountain Field Station of the Central Radio Propagation Laboratory, National Bureau of Standards, conducts continuous propagation studies on frequencies in the range from 92 to 1046 Mc. Fig. 1 is a pictorial representation of all facilities used in these studies. The transmitters for continuous measurement are located on Cheyenne Mountain near Colorado Springs, Colorado. The transmitter power output is 2 kw for 92 and 210.4 Mc transmissions from a location at approximately 7500 ft elevation. The antennas are of the corner-reflector type. Similar transmitters and antennas for 100 and 192.8 Mc are located at approximately 8800 ft elevation. In addition thereto, a 4 kw UHF transmitter using a klystron final stage is located at the 8800 ft elevation and transmits a 1046 Mc signal employing a slot-fed horn type antenna.

All transmissions are continuous wave, and are horizontally polarized.

The abrupt slope of Cheyenne Mountain simulates air-to-ground communications, as the transmitters are from 2000 to 3000 ft above the relatively level prairie immediately east of Cheyenne Mountain. Fixed receiving sites are located along a radial extending approximately 105 degrees east of true north from Cheyenne Mountain. The transmissions from the Cheyenne Mountain site on 100, 192.8, and 1046 Mc to the receiving sites at Kendrick (50-mile path) and Karval (70-mile path) are within the radio horizon, and have been carried out continuously since January 1952 except for outages due to equipment failure. Results obtained thereby are within the scope of this paper. Suitable VHF and UHF receivers associated with dipole antennas, Esterline-Angus graphic recorders and calibration standards are employed at these receiving sites.

In order to point out a definite distinction in the appearance of graphical recordings of optical and non-optical signals, Fig. 2 is added to show the difference in the 100 Mc picture as received at Kendrick and Karval from Cheyenne Mountain (optical) and the Camp Carson site at the base of Cheyenne Mountain (non-optical). The transmitters were operated alternate hours, and the distinction between the signals is very clear, showing no appreciable short-term variations*

---

*Within the scope of this paper "short-term" variations are defined as changes in signal intensity within each hour.

in the received signal from Cheyenne Mountain summit, whereas the signal from the Camp Carson site shows a substantial amount of fading. The analysis of data collected over the period of one year shows that with the equipment available, no short-term variations of any importance are evident for any of the paths within the radio horizon, except for prolonged space-wave fadeouts occurring on 1046 Mc which will be discussed later on.

2. METHODS OF ANALYSIS

Tropospheric fields within the frequency range covered in this report exhibit short-term variations which may be described by fading range and fading rate as well as long-term variations which may conveniently be described by diurnal and month-to-month trends in the variations of hourly median values. It has been pointed out before that with the equipment available no appreciable short term variations were determined. The hourly median, therefore, was used as a basis of studying the variations in the received signal occurring from day to day and month to month. The following procedures are followed in the analysis.

From the Esterline-Angus recordings (see Fig. 2 for an example) the median value of the field for each individual hour is determined by inspection. For each site and each frequency these hourly median values are tabulated using suitable units. Allowance is made for line losses at the transmitting and receiving end, antenna gains as measured or assumed, and comparison of signal generators used in calibration of the equipment to common standards. This permits all median values to be expressed in attenuation relative to the free space field. The value "A" which signifies attenuation relative to the free space fields in decibels is taken as positive if the measured field is less than the free space fields.

For each month the hourly median values for each path and each frequency are divided into eight groups in accordance with successive three-hour periods of the day. Thereby characteristic distributions of hourly median values are obtained for eight periods within the 24 hour day, and used as a basis for diurnal variation analysis. The distributions of all hourly medians over the period of one month serves as a basis for determining month-to-month variations.

From the tabulations of hourly median values, distributions are computed, and plotted on probability graph paper. Samples of such distributions are shown in Fig. 3, comparing for the month of September (1952) a typical nighttime period (midnight to 3 AM) to a typical daytime period (noon to 3 PM). It is shown that a diurnal variation of the hourly median level on all frequencies is apparent, and comparison of the distribution curves for the day and nighttime period shows a difference in slope as well as a difference in median level.

Similar distributions are drawn for all other three-hour periods as well as for the aggregate hours of each month without regard to the time of day. Each curve furnishes a monthly median value which denotes the signal value exceeded by 50% of all hourly medians comprising the distribution, and a difference (in decibels) of the values exceeded by 90% and by 10% of all hourly medians which may be termed the interdecile range. This procedure was followed in preference to determining a quantity like the standard deviation as the distributions obtained from the data evaluation are only approximately normal.

3. RESULTS OF ANALYSIS

Fig. 4 shows the diurnal variations of monthly medians taken from the distribution curves for the eight three-hour periods for three frequencies at both receiving sites within the radio horizon, and compares results for a typical winter and summer month. It is significant that the diurnal variations are more substantial in summer on the VHF frequencies, but the 1046 Mc data show not only substantially less diurnal changes than the lower frequencies but also seem to reverse the general trend of higher summertime signals. This may be due to the choice of the months for which data are presented here. The month-to-month trends will be discussed later.

Observed interdecile ranges taken from the aggregate distribution curves for each month are shown in Fig. 5. Broken lines do not denote extrapolations, but indicate that one or several months of data are missing between others for which results are available. For March, October, November, and December of 1952, no 1046 Mc data are available but values for January 1953 were determined and serve as endpoints of the broken lines. Fig. 6 shows (in solid lines) the month-to-month trend of monthly medians for four three-hour periods which contain the hours 0200, 0800, 1400, and 2000 and are designated by these numerals. The use of these particular periods is dictated by the availability of meteorological data for these hours.

Although it has been planned to observe pertinent meteorological data over the Cheyenne Mountain path simultaneously with field strength measurements in order to correlate changes in field with changes in atmospheric conditions, very little data of this kind are available at the present time. However, observed monthly distributions of the refractive index gradient determined at Lowry Air Force Base near Denver, Colorado, were available for the year 1951. Lowry Base is about 70 miles north of the Cheyenne Mountain paths discussed in this paper, and it was felt that in spite of the geographical separation and of the time difference involved (1951 meteorological data and 1952/53 field strength measurements) a study should be made to determine correlation, if any.

Expected values of field strength were computed for 100, 192.8, and 1046 Mc using methods developed by Norton[1/] and further elaborated for the Cheyenne Mountain path by the author. The resultant values of field computed for the median refractive index gradient applicable to each month at each of the four daily periods for which the Lowry data were available are shown in Fig. 6 by the broken lines. In comparing the measured month-to-month field strength data with the computed values based on the Lowry Field meteorological data, it should be noted that meteorological data were available for April, June, August, October, December, and January only. Disregarding the absolute differences between measured and computed monthly median values, correlation coefficients between them may be determined for each frequency at each site using only those months for which meteorological data were available. This was done with the following results[2/]:

Frequency	Kendrick Correlation Coefficient	Kendrick 90% Fiducial Limits	Karval Correlation Coefficient	Karval 90% Fiducial Limits
100Mc	0.034	-0.314 to +0.374	0.853	+0.720 to +0.926
192.8 Mc	0.697	+0.449 to +0.845	0.704	+0.460 to +0.849
1046 Mc	0.045	-0.349 to +0.463	0.284	-0.159 to +0.638

Although it may not be proper at all to draw conclusions from a correlation of measured data varying over such a small range with computations based on conditions of the previous year, the high degree of correlation obtained on 192.8 Mc at both sites and on 100 Mc at Karval may be significant. The absence of correlation on 1046 Mc at both sites is probably an indication that characteristics of the atmosphere other than its linear gradient are responsible for these changes in hourly median levels.

Signal variations observed at Kendrick on 100 Mc are often small enough to be obscured by equipment instabilities and calibration changes, and the absence of correlation in this particular case may possibly be explained thereby.

Naturally a well coordinated meteorological program should permit similar studies to be made with a much higher degree of reliability.

4. PROLONGED SPACE-WAVE FADEOUTS ON 1046 Mc

While it may be stated that the signals within the radio horizon may be described adequately by their hourly median values (in the absence of any significant short-term variations), experimental evidence is available which shows comparatively large fades of the 1046 Mc signal occurring at Kendrick as well as at Karval. These fades last from several minutes to well over two hours and range in magnitudes from 5 to more than 20 decibels below the average signal before and after the fadeout. Fig. 7 shows samples of recording charts for September 4, 1952, which not only show a characteristic fadeout occurring at both sites on 1046 Mc, but also the absence of any similar effect on the other frequencies. These fades, however, do not always occur simultaneously at both sites. A study of the frequency of occurrence shows that the fadeouts are considerably more frequent in summer than in winter (Fig. 8), and that more than 90% occur between the times of two hours before sunset, and two hours after sunrise (Fig. 9). Additional studies of this problem are in progress, and will be reported separately.

5. CONCLUSIONS AND RECOMMENDATIONS

Although the data presented show certain diurnal and month-to-month variations, it appears to be highly desirable to obtain additional information in order to ascertain the character of diurnal variations during successive years. What has been termed "month-to-month variations" could probably more adequately be described as variations due to changing air masses, and only a closely coordinated meteorological program can provide the ultimate answer: namely, a method of predicting the fields on the basis of weather information. This also points to the necessity of having several years of measured data available in conjunction with the meteorological information. Diurnal and month-to-month variations of hourly median values and the interdecile range of the received signals within the radio horizon are operationally not as significant as for larger distances. Overall variations are considerably less than 10 decibels, and the prolonged space-wave fadeouts observed in the 1000 Mc range do not occur on the lower frequencies.

Several possible explanations have been offered which should account for the occurrence of prolonged space-wave fadeouts, but they all depend on further meteorological studies which will be carried out during the summer of 1953 by the Central Radio Propagation Laboratory as well as by other agencies.

REFERENCES

1/ K. A. Norton, "Transmission Loss of Space Waves, Propagated Over Irregular Terrain," Trans. IRE Professional Group on Antennas and Propagation, No. PGAP-3, August, 1952.

2/ George W. Snedecor, "Statistical Methods," The Iowa State College Press, Ames, Iowa, p. 150, 1948.

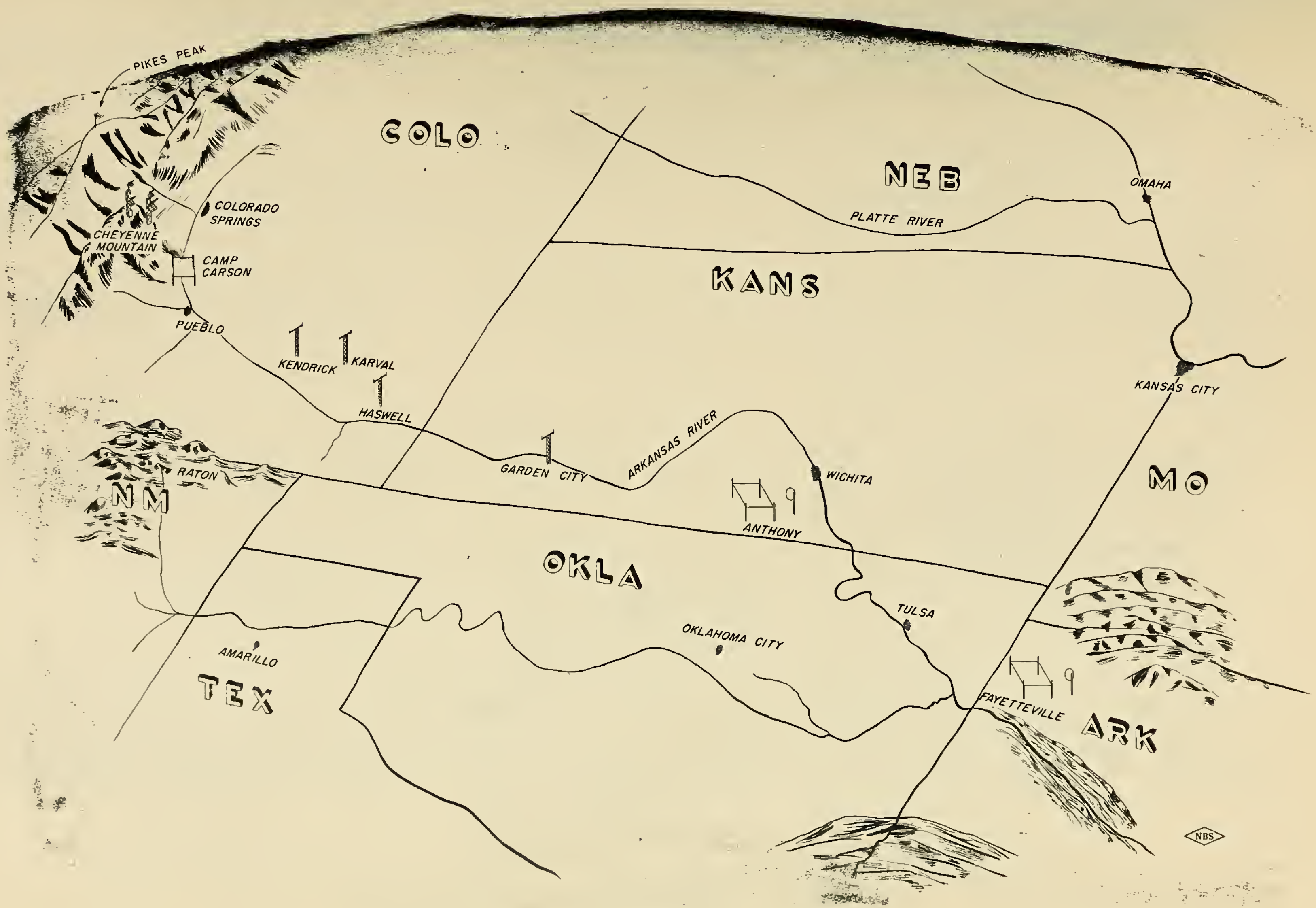

PIKES PEAK
COLO
NEB
OMAHA
COLORADO SPRINGS
CHEYENNE MOUNTAIN
CAMP CARSON
PLATTE RIVER
KANS
PUEBLO
KENDRICK
KARVAL
HASWELL
KANSAS CITY
ARKANSAS RIVER
RATON
NM
GARDEN CITY
WICHITA
MO
ANTHONY
OKLA
TULSA
OKLAHOMA CITY
AMARILLO
TEX
FAYETTEVILLE
ARK
NBS

FIG. 1

COMPARISON OF RECEIVED SIGNAL
ON 100 Mc FOR OPTICAL AND
NON-OPTICAL TRANSMISSION PATHS

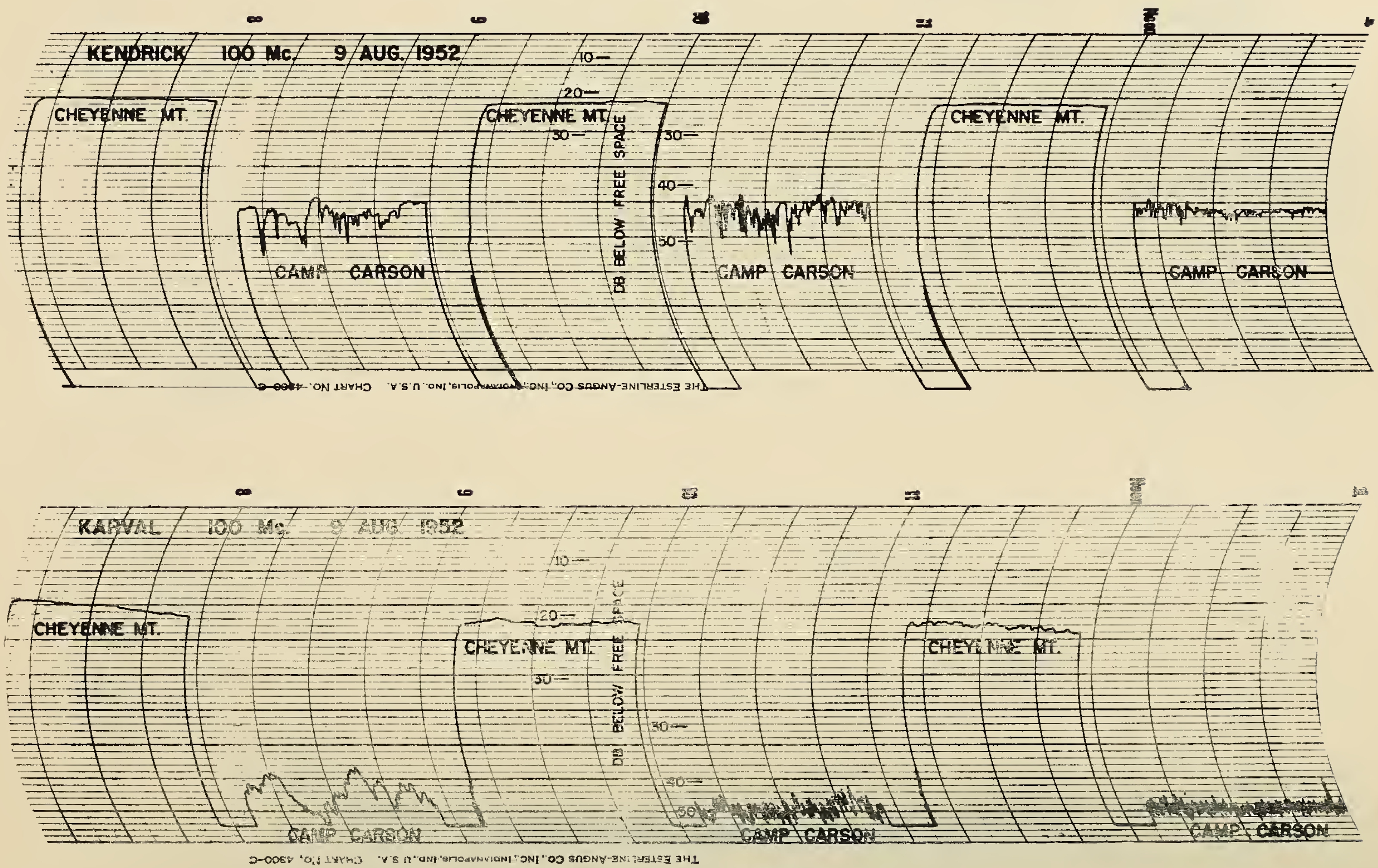


FIGURE 2

NBS

DISTRIBUTIONS OF HOURLY MEDIANS FOR CHEYENNE MT. OPTICAL PATHS

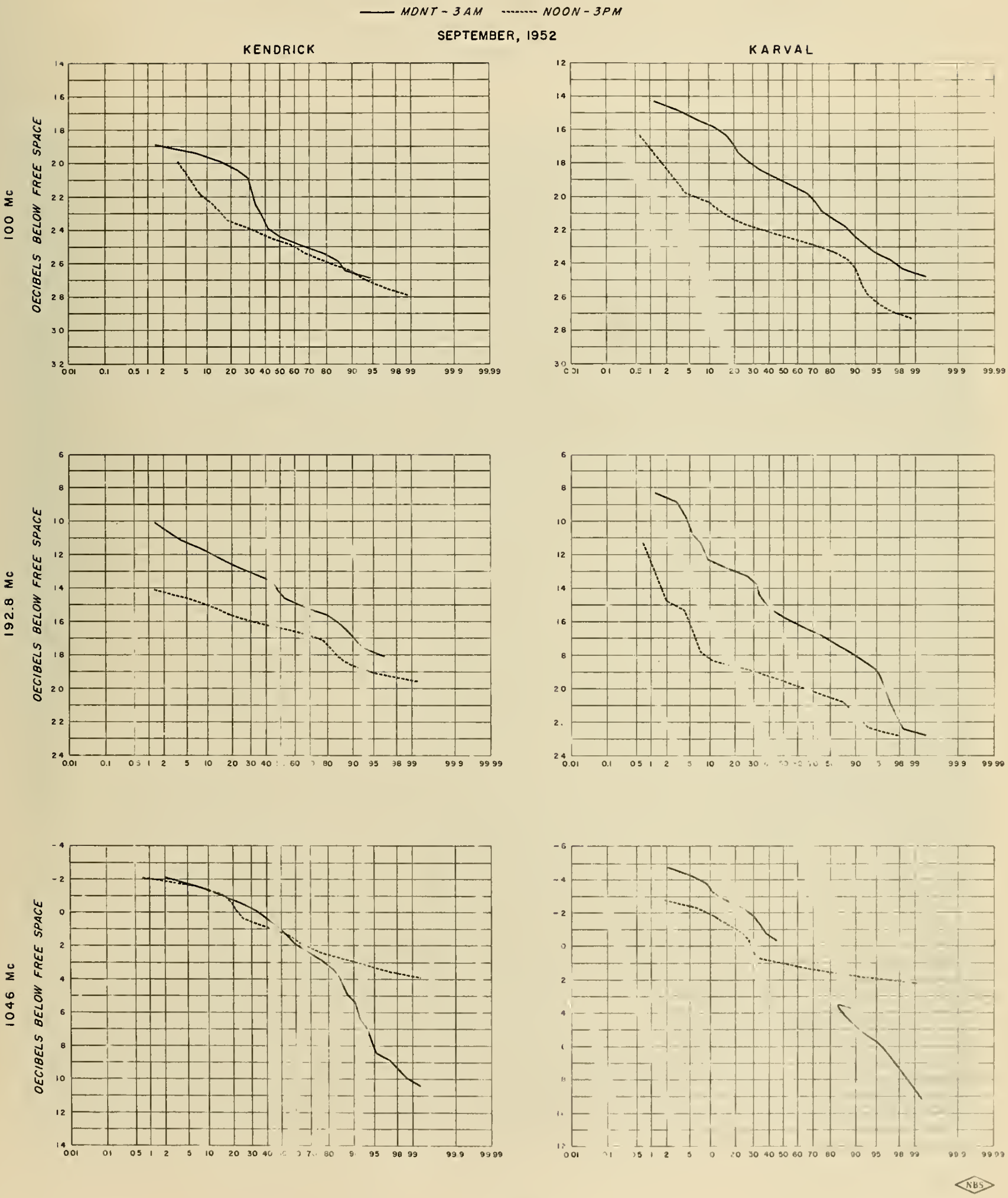


FIGURE 2

DIURNAL VARIATIONS OF MEDIAN SIGNAL LEVELS
CHEYENNE MT. OPTICAL PATHS

BASED ON DISTRIBUTIONS OF HOURLY MEDIANS FOR MONTHS SHOWN

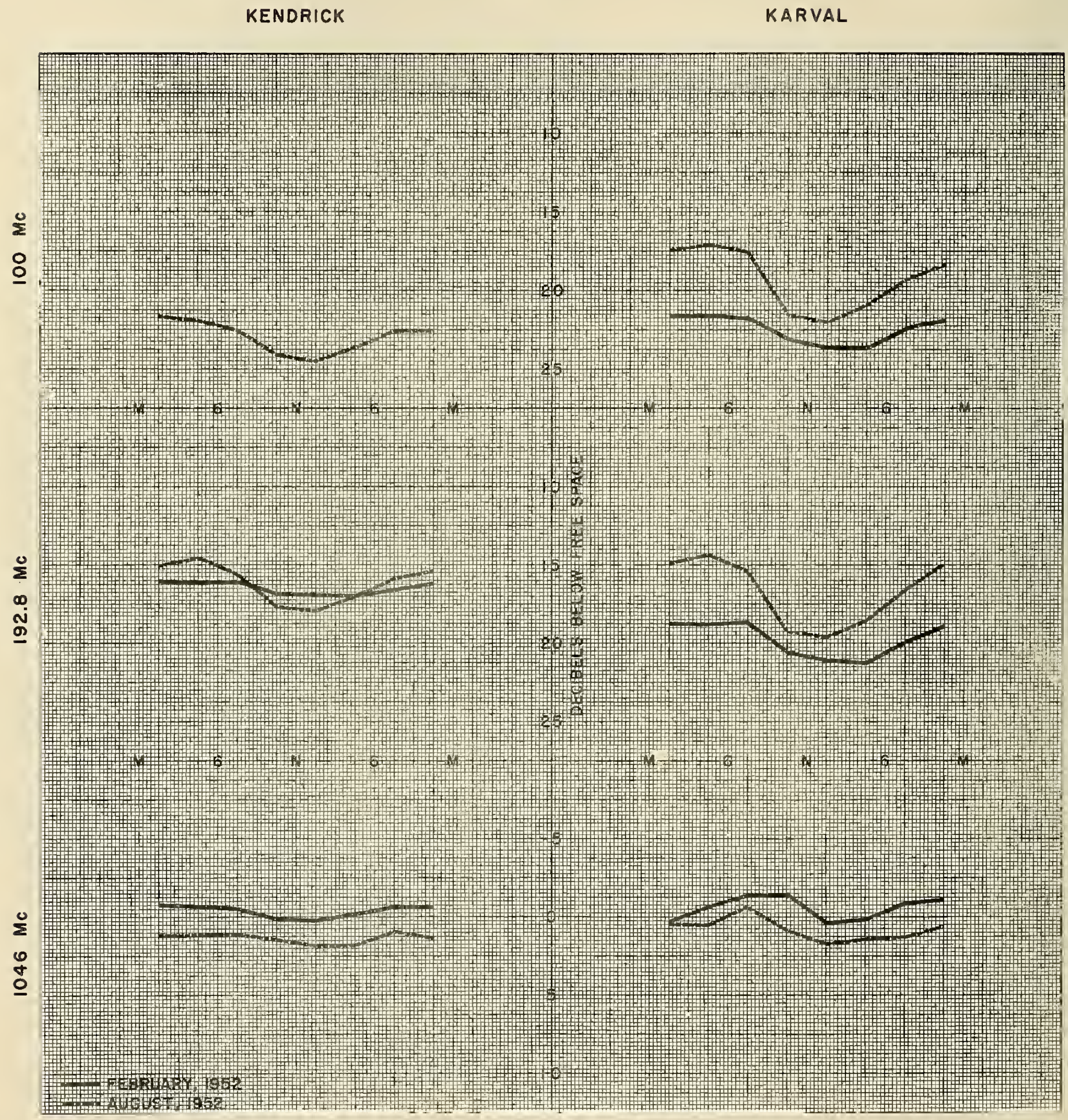


FIGURE 4

MONTH-TO-MONTH VARIATIONS OF INTERDECILE RANGE OF HOURLY MEDIANS FOR CHEYENNE MT. OPTICAL PATHS

THE ORDINATES DESIGNATE DIFFERENCES (IN DECIBELS) OF THE LEVELS EXCEEDED BY 10% AND 90% OF ALL HOURLY MEDIANS FOR EACH MONTH

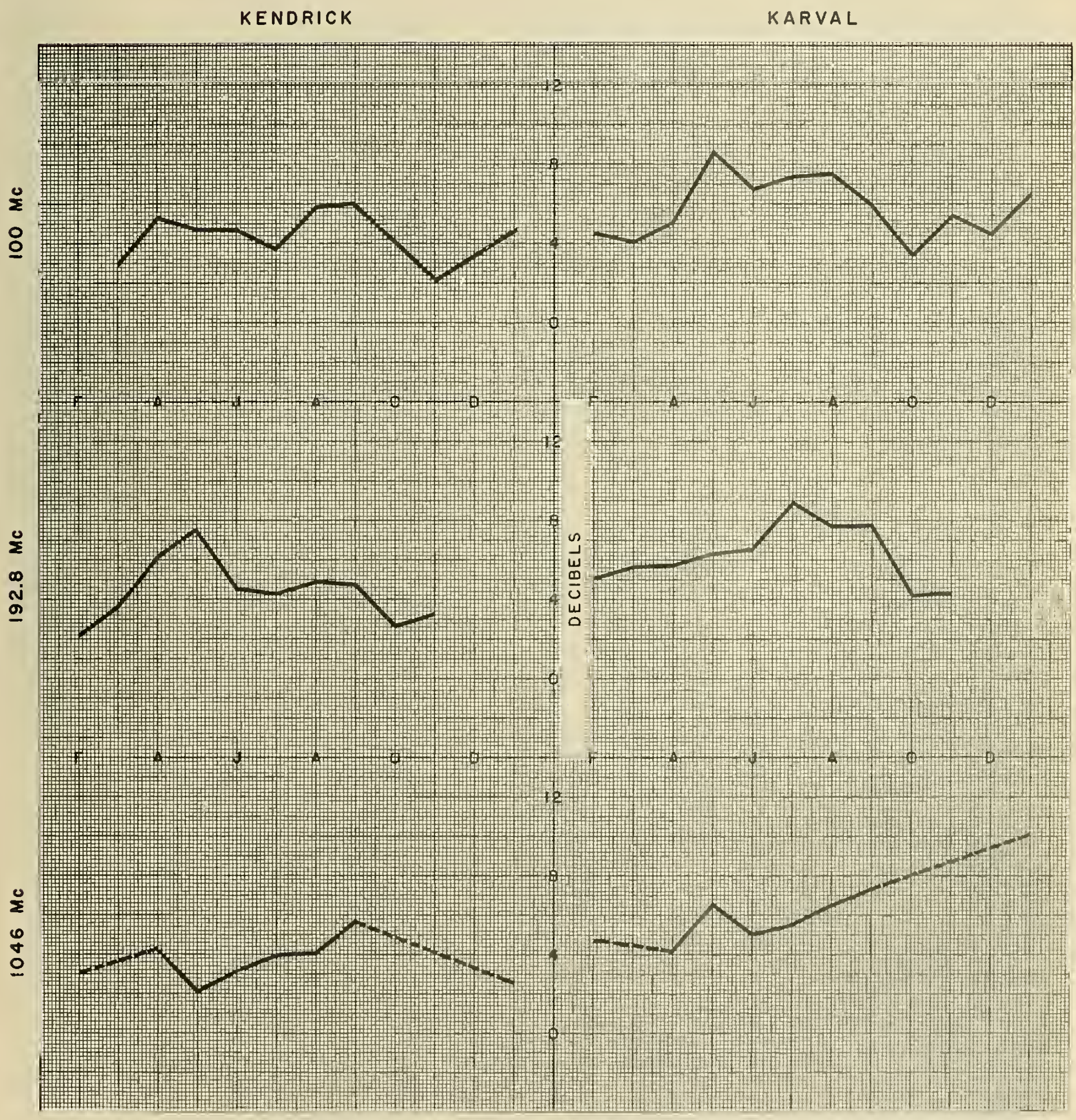


FIGURE 5

MONTH-TO-MONTH VARIATIONS OF COMPUTED AND MEASURED MEDIAN SIGNAL LEVELS FOR TWO OPTICAL PATHS

BASED ON MONTHLY DISTRIBUTIONS OF HOURLY MEDIANS

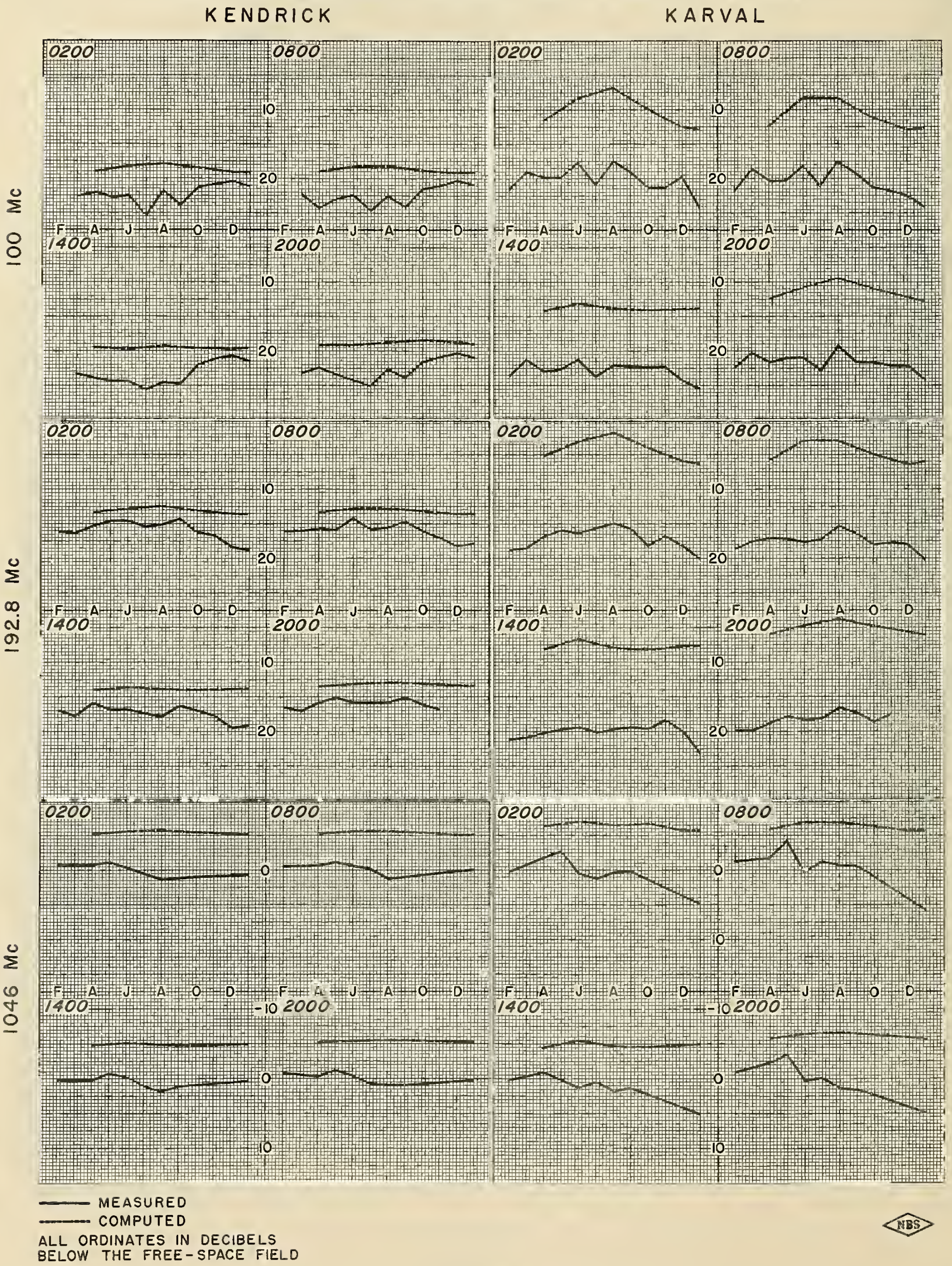


FIGURE 6

RECORDING CHART SAMPLES
CHEYENNE MT. OPTICAL PATHS

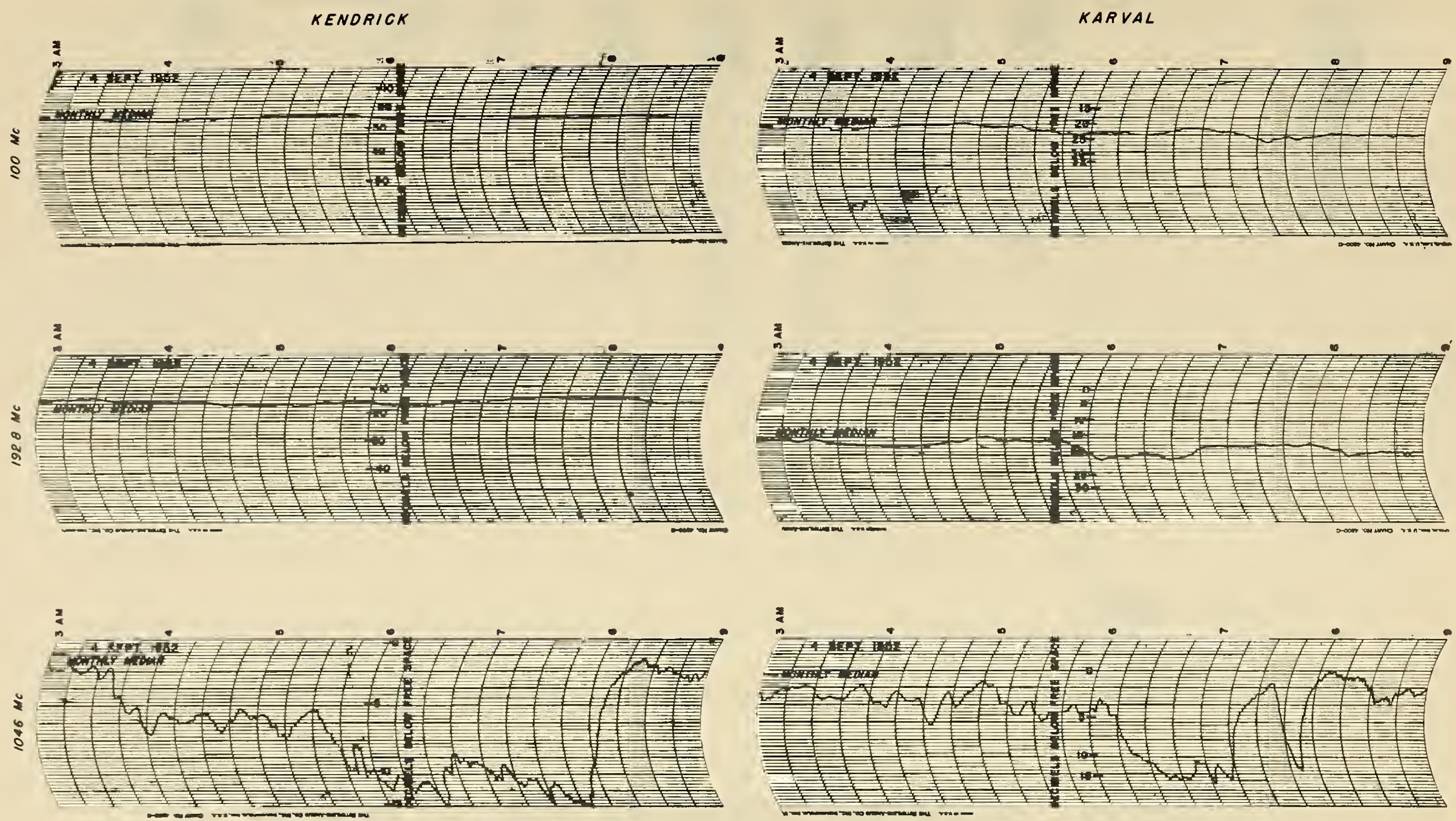


Figure 7

SEASONAL TREND IN NUMBER OF OBSERVED SIGNAL DIPS ON 1046 Mc FOR CHEYENNE MT. OPTICAL PATHS

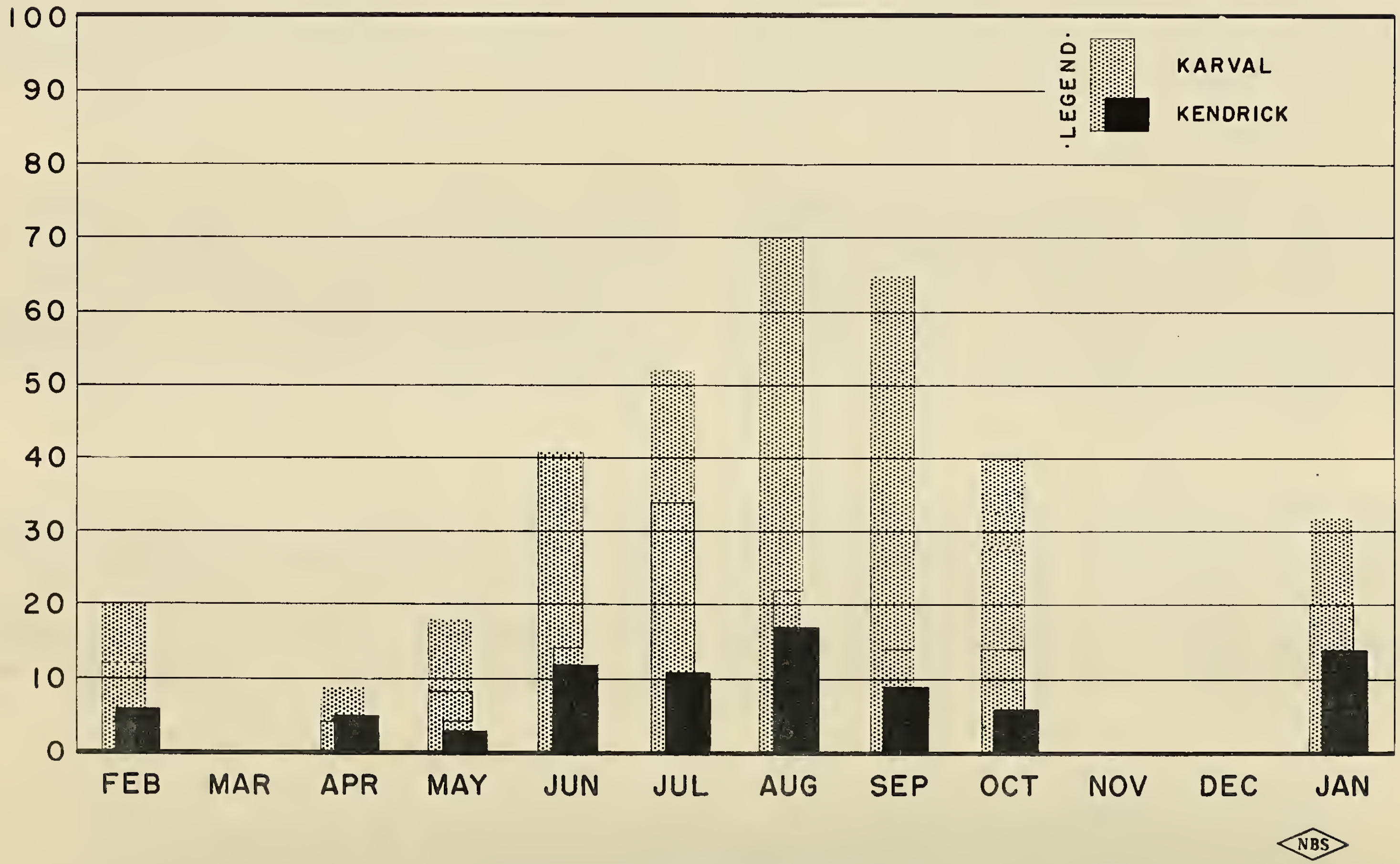


FIGURE 8

Supplement VI

PROPAGATION OF RADIO WAVES OVER LAND AT 1046 Mc

By

A. P. Barsis, B. R. Bean, J. W. Herbstreit, K. O. Hornberg, and K. A. Norton

Supplement VI

PROPAGATION OF RADIO WAVES OVER LAND AT 1046 Mc

(Report for the Air Navigation Development Board)

By

A. P. Barsis, B. R. Bean, J. W. Herbstreit, K. O. Hornberg, K. A. Norton
National Bureau of Standards, Boulder, Colorado

INTRODUCTION AND SCOPE

Background

The Air Navigation Development Board in discharge of its duties as expressed in its Charter, initiated an investigation of radio wave propagation in the 960-1600 Mc frequency band and placed the supervision of such a project under the Central Radio Propagation Laboratory of the National Bureau of Standards.

The most important aspect of this study of radio wave propagation is its bearing on the problem of assessing the reliability of air-to-ground communications or radio navigation. Most of the following report deals either directly or indirectly with this important problem.

Furthermore, inasmuch as the frequencies to be used within this band must necessarily be recurrent to conserve the frequency spectrum, the distance between co-channel facilities must be determined by the interference within the service area of one station by transmissions from another station or stations on the same frequency. In view of the fact that evidence existed wherein transmissions at these frequencies did not behave strictly as line-of-sight but that interference fields existed well beyond line-of-sight, the National Bureau of Standards originated the Cheyenne Mountain Field Station in Colorado Springs, Colorado to investigate the propagation phenomena associated with simulated air-to-ground transmissions, not only at distances within line-of-sight where the question of service reliability is involved, but also at points far beyond the radio horizon which may be involved in the solution of mutual interference problems.

The experiments conducted along these lines were to be the first phase of a long range program and were to be of a continuous nature for a period of at least one year to determine adequately the nature of the diurnal and seasonal variations of the radio field intensity.

In view of the realization that climatological conditions vary greatly throughout this country and the world and that the propagation data assembled over the Cheyenne Mountain path would have to be very carefully interpreted for extension to other areas, a radio meteorological program was considered advisable in conjunction with the Cheyenne Mountain experiments. The meteorological phase of the program is designed to test the accuracy of recent developments in radio meteorology analysis and to improve these methods on a climatological basis.

The technical supervision of the ANDB project within CRPL was assigned to Mr. J. H. Chisholm from the beginning of the project until November, 1951, when he resigned from the National Bureau of Standards. Mr. G. R. Chambers was then assigned the supervision of the ANDB project in addition to the 100-1000 Mc program operating concurrently. Upon the resignation of Mr. Chambers in June, 1952, Mr. K. O. Hornberg was assigned the duties held by his predecessor and is currently in charge.

Scope of this Report

The purpose of this report is to present the experimental data on 1046 Mc obtained at the Cheyenne Mountain Field Station for the period February 1, 1952 through January 31, 1953. Continuous recordings were not made prior to this period and consequently any previous data are not considered. In addition, this report includes the analysis of diurnal and seasonal variations in hourly median signal levels, the analysis of variations in instantaneous signal levels and the analysis of prolonged space- wave fadeouts within the radio horizon for the period investigated, an analysis of the effects of irregular terrain at points within the radio horizon, an analysis of the scattered signals at points far beyond the radio horizon, including estimates of the expected effective gains of large antenna arrays, the required spacing for diversity arrays and the effective intelligence bearing bandwidths of the propagation paths. Finally, as a result of a recent investigation of propagation over high mountain ridges, an analysis is presented of the "obstacle gains" expected at 1000 Mc in mountainous terrain.

DESCRIPTION OF FACILITIES

Transmission Paths

The 1046 Mc Cheyenne Mountain project is shown pictorially in Fig. 1 with the transmitting site located on Cheyenne Mountain at an elevation of 8800 feet above mean sea level and several fixed and semi-mobile recording sites in eastern Colorado, Kansas, and Arkansas. Figs. 2a, b, and c show the terrain profiles along the transmission paths from the transmitter to each of the three fixed recording sites located at Kendrick, Colorado (49.3 mi), Karval, Colorado (70.2 mi), and Haswell, Colorado (96.6 mi). Fig. 2d shows the terrain profile out to Garden City and Anthony, Kansas. The definition is given on Fig. 2d of an angle, θ, which we have used throughout this report to characterize a particular transmission path. This is simply the angle between the radio horizon lines in the great circle plane. Transmission paths within the line-of-sight will be characterized by negative values of θ while positive values of θ correspond to non-optical paths. The usefulness of the parameter θ in tropospheric propagation lies in the fact that it can be used (largely independently of the antenna height h provided h is sufficiently great) to describe fading characteristics and transmission loss relative to free space, while at the same time it can be used to extrapolate the results of propagation measurements to a terminal at an arbitrarily high elevation. Fig. 2e demonstrates how the same angle θ can characterize various transmitting heights h_{t_1}, h_{t_2}, and h_{t_3}, while Figs. 11c and 12e show how the experimental data can be described in terms of the parameter θ, being largely independent of the heights of the terminals. This principle is of great importance in engineering air-to-ground communication and navigation systems. The method of calculating θ for transmission paths over irregular terrain is discussed in Appendix I and the value of θ for our 1046 Mc transmission paths are given in Table I, based on an assumed effective radius of the earth equal to four-thirds of its actual value to allow for standard air refraction. The terrain profiles of Figs. 2a, b, c, and d are based on standard atmospheric refraction and show that the Kendrick and Karval sites are within line-of-sight, while the Haswell site is just beyond line-of-sight and in the diffraction zone and the Garden City location is well beyond line-of-sight and considered out of the diffraction zone and in the scattering region for reception. An examination of these terrain profiles in the light of Rayleigh's criterion of roughness indicates that the actual terrain is quite rough compared to the wavelength of transmissions, although the transmission path appears visually to be as level as one is likely to find in siting VHF ground terminals. The practical significance of this roughness is discussed in detail in a later section of this report.

The soil condition along the transmission path in eastern Colorado and western Kansas is quite arid, being utilized for cattle grazing and dry farming. In central Kansas, in the vicinity of Garden City, the land becomes less arid and wheat farming predominates.

The prevailing wind conditions are usually from the south with turbulence at all levels extending from the mountain region to the Colorado-Kansas border. Wind velocities in the Colorado Springs and Haswell, Colorado areas are generally in excess of 15 mi per hr with gusts exceeding 50 mi per hr quite frequently. The area is one of conflict between the settled conditions of mountain induced subsidence and solar induced turbulence. The area is under intensive study by meteorologists as the birthplace of tornadoes and the Geophysical Research Directorate is planning an intensive turbulence study to be conducted in this area next summer. Although the site for these propagation measurements was chosen primarily for a high mountain site, subsequent investigation has revealed the area to be an ideal location for radio-meteorological studies due to the heterogeneous meteorology available.

Transmitting Facilities

The 1046 Mc 4 kilowatt cw transmitter is located on Cheyenne Mountain near Colorado Springs, Colorado with the transmitting antenna at an elevation of 8760 feet above mean sea level or approximately 3000 feet above the average elevation of the plains at the base of the mountain. Figs. 3a and 3b are photographs of the transmitter site and a close-up of the antenna. Fig. 3c is a photograph of the klystron transmitter. A block diagram of the 1046 Mc transmitting facility is shown in Fig. 3d. A more detailed description of the klystron transmitter can be found in NBS Report 1826. 1/

The horizontally polarized transmitting antenna is of the slot-fed-horn type and has a gain of 26 db with respect to an isotropic radiator. This gain is obtained through the use of half-power horizontal and vertical beam widths of 18 and 6 degrees, respectively.

Recording Facilities

The 1046 Mc transmissions are recorded continuously 24 hours per day, seven days a week, at four fixed locations namely Kendrick, Colorado; Karval, Colorado; Haswell, Colorado, and Garden City, Kansas. Short term continuous recordings are made during mid-summer and mid-winter at Anthony, Kansas and Fayetteville, Arkansas. Inasmuch as the Anthony and Fayetteville sites are far beyond the radio horizon, less emphasis has been placed on this part of the program.

Pertinent recording site data are given in Table I.

TABLE I

Site	Miles from Transmitter	θ	True Bearing from Trans.	Elevation Above MSL - Feet	Antenna	Antenna Height Above Ground-Feet
Kendrick	49.3	-0.221°	105.569°	5260	Dipole	42.7
Karval	70.2	-0.130°	97.059°	5060	Dipole	42.7
Haswell	96.6	0.102°	105.255°	4315	Dipole	42.7
Garden City	226.5	1.532°	105.247°	2855	Dipole	42.7
Anthony	393.5	3.422°	103.352°	1335	Parabolic Reflector	10.0
Fayetteville	616.3	5.638°	103.670°	1325	Parabolic Reflector	38.0

Figs. 4a and 4b are photographs of typical fixed and mobile recording sites, respectively. A block diagram of a recording site is shown in Fig. 4c. Fig. 4d is a photograph of the recording equipment including receiver, calibrating signal generator, frequency standard, chart recorder and time totalizing recorder.

A block diagram of the Brooklyn Polytechnic Research and Development Co., Inc. type 856-X narrow-band receiver is shown in Fig. 4e.

Further details of the recording facilities are given in NBS Report 1826. 1/

RESULTS OF MEASUREMENTS

General Discussion

Results of continuous measurements on 1046 Mc for all transmission paths are available in the form of Esterline-Angus graphical records for all fixed receiving sites while additional microfilm records of time totalizer data are available for the Garden City and Anthony sites. Figs. 5a to 5d are samples of Esterline-Angus charts showing representative recordings for typical night and afternoon periods during winter and summer at each of the four fixed sites. Fig. 5e shows the only data available out of a period of several weeks recordings at Fayetteville, Arkansas. Although it has not been possible as yet to undertake a detailed numerical study of fading rates at the various sites, inspection of the chart samples indicates an increase in the fading rate with distance from the transmitter beyond the radio horizon. The rapid fading at Garden City makes analysis of the Esterline-Angus charts quite difficult, and time totalizers are used for this reason as they provide means for interpretation of rapidly fading signals. At Haswell, which is some 20 miles beyond the radio horizon, the amount and rate of fading has been found to vary with the time of the day and the season, and is undoubtedly strongly influenced by prevailing atmospheric conditions. Execution of the meteorological program planned will provide a basis for a detailed study of the correlation between the character of the received signal, and the status of the lower atmosphere.

Significant signal variations at the two sites within the radio horizon appear to be irregular in nature, and, in general, are not characterized by single fading rate for this range. Observed prolonged space-wave fadeouts will be discussed in a subsequent portion of this report.

Hourly Medians

For purpose of data analysis and presentation, the hourly median value expressed in decibels below free space value was used. This constitutes a measure of the field or power available for 50% of each hour for which recordings are available. Hourly median values are determined from the Esterline-Angus and time totalizer records, and tabulated for each receiving site. In order to determine diurnal variations of the received power, the hourly median values for each month at each receiving site are separated into eight three-hour periods (midnight to 3 AM, 3 AM to 6 AM, etc.) and data for each of the three hour periods have been investigated separately.

Figs. 6a to 6j show over-all distributions of hourly medians for each month for which data were available. These distributions are plotted on probability graph paper, and show the number of hours of recordings which serve as a basis for each of the curves shown. It is seen from the graphs that the curves approach lines representing normal distributions with varying slopes. For each month and each site, therefore, an over-all monthly median, and the observed range of hourly median values may be determined, and these serve as a basis for characterizing the seasonal variations of these values at each site, and of the measured dependence of the signal on the distance from the transmitter. The ratio of hourly median values exceeded for 10% and for 90% of all hours is used as a measure of the variance of the monthly signal.

Fig. 6k shows distributions of hourly medians for each site for all hours of the entire year for which recordings were available.

Fig. 6l shows the distribution of hourly medians recorded at the Anthony site during August, 1952.

Typical distributions for nighttime and afternoon diurnal periods are shown in Figs. 7a to 7d. Distributions of hourly medians during the months of February, June, and September are shown for the periods 3 AM to 6 AM, and noon to 3 PM. It is believed that the larger variance of the transmission loss during the early morning hours at Kendrick and Karval, particularly in September, is largely due to the occurrence of prolonged space-wave fadeouts at these locations. A monthly median for each three-hour period, and a corresponding measure of its variance may be determined from these distributions, and equivalent graphs (not shown) drawn for all three-hour periods for all months form the basis for Figs. 8 and 9.

Figs. 8a and b use the monthly medians for each three-hour period to depict the diurnal change in the hourly median values. Each set of curves shows the diurnal signal change at the four sites for each month, and thus permit observation of diurnal changes with distance, and over the season. Diurnal changes were not shown in cases where sufficient data for individual three-hour periods were not available for a particular site at a certain month. Similarly, Figs. 9a and b show the diurnal changes of the variance of hourly medians as obtained from the monthly distributions.

Fig. 10a shows the seasonal variation of median signal levels comparing the over-all monthly values to the typical night and afternoon periods. In studying this graph one should bear in mind that no data at all were available for March, November, and December, and incomplete data for some of the other months at several of the receiving sites.

Fig. 10b shows the seasonal trend of the variances drawn for the same period as Fig. 10a. The same restrictions with regard to the incompleteness of the data apply.

Finally, Figs. 11a and b show the over-all monthly medians and their variances versus distance. The points shown for each site are taken from the monthly distributions (Figs. 6a to j). The line on the graph connects points taken from the aggregate yearly distributions for each site (Fig. 6k).

Fig. 11c shows the variation of the median attenuation for the month of August relative to the free space value as a function of the angular distance, θ. This illustrates, in the case of the 100 Mc data, how attenuations measured at different antenna heights varying from 30' to 7800' above local terrain all lie on a single curve when plotted as a function of θ.

Distributions of Signal Levels Within the Hour

The material discussed so far is based on the hourly median of the received signal as its unit of evaluation; however, signal variations occurring within the hour are important as well. They may be described by fading range and fading rate. As detailed studies of the fading rate are not yet available, the following discussion will be restricted to fading range problems. It has been found convenient to define fading range within each hour as the ratio of power levels (expressed in decibels) exceeded for 90% and 10% of each hour.

The month of August, 1952, has been selected for detailed studies of fading range. For all sites beyond the radio horizon (Haswell, Garden City, and Anthony), distributions of signal levels were obtained for each individual hour. These distributions were tabulated with reference to the median value of signal observed for each hour, and the distribution of deviations from the median was averaged over the entire month for each hour, i. e. the 30 percentages of time for each deviation level corresponding to the 30 days of the month were averaged to determine a percentage typical of that month and deviation level. These average distributions were then plotted on Rayleigh graph paper. Samples of these average distributions are shown on Fig. 12a, together with a straight line representing the ideal Rayleigh distribution. From each distribution the fading range is read off as the ratio (in decibels) exceeded for 90% and 10% of each hour, and compared with the range for an ideal Rayleigh distributed signal (13.4 db). Figs. 12b, c, and d show the diurnal variation of the hourly medians and of the fading range for the three sites beyond the radio horizon. Fig. 12e shows the variation of fading range with the angular distance, θ.

REFERENCES

1/ G. R. Chambers, J. W. Herbstreit and K. A. Norton, "Preliminary Report on Propagation Measurements from 92-1046 Mc at Cheyenne Mountain, Colorado," NBS Report 1826, July 23, 1952.

2/ P. A. Sheppard, "The Structure and Refractive Index of the Lower Atmosphere," Meteorological Factors in Radio-Wave Propagation, Report of a Conference Held on April 8, 1946, at The Royal Institution, London, by the Physical Society and The Royal Meteorological Society.

3/ K. A. Norton, "Transmission Loss of Space Waves Propagated Over Irregular Terrain," Transactions of the IRE Professional Group on Antennas and Propagation, PGAP-3, pp. 152-166, August, 1952. Also NBS Report 1737, June 16, 1952.

4/ K. A. Norton, "The Calculation of Ground-Wave Field Intensity Over a Finitely Conducting Spherical Earth," Proc. IRE, Vol. 29, pp. 623-639, December, 1941.

5/ H. G. Booker and W. E. Gordon, "A Theory of Radio Scattering in the Troposphere," Proc. IRE, pp. 401-412, Vol. 38, No. 4, April, 1950.

6/ Harold Staras, "Scattering of Electromagnetic Energy in a Randomly Inhomogeneous Atmosphere," Jour. App. Physics, pp. 1152-1156, Vol. 23, No. 10, October, 1952. Also NBS Report 1662, May 12, 1952.

7/ J. W. Herbstreit, K. A. Norton, P. L. Rice, and G. E. Schafer, "Radio Wave Scattering in Tropospheric Propagation," 1953 Institute of Radio Engineers Convention Record; also NBS Report 2459, April 15, 1953.

8/ W. E. Gordon, "Radio Scattering on Optical Paths," Paper presented at Symposium on Tropospheric Wave Propagation Within the Horizon, Navy Electronics Laboratory, San Diego, Calif., March 30-April 1, 1953.

9/ K. A. Norton, "Propagation in the FM Broadcast Band," Advances in Electronics, Vol. I, pp. 406-408, Academic Press, Inc., New York, 1948.

10/ K. A. Norton, "Propagation Over Rough Terrain," Report of Symposium on Tropospheric Wave Propagation at the U. S. Navy Electronics Laboratory, San Diego, Calif., pp. 101-105, July, 1949.

11/ S. O. Rice, "Statistical Fluctuations of Radio Field Strength Far Beyond the Horizon," Proc. IRE, Vol. 41, No. 2, pp. 274-281, February, 1953.

12/ Saburo Matsuo, "The Method of Calculating VHF Field Intensity and Research on Its Variations," Report of the Electrical Communication Laboratory 621.39.001.6(047.3), Ministry of Telecommunications, Tokyo, Japan, August, 1950.

13/ J. C. Schelleng, C. R. Burrows and E. B. Ferrell, "Ultra Short Wave Propagation," Proc. IRE, Vol. 21, pp. 427-463, March, 1933.

14/ K. A. Norton, "Transmission Loss in Radio Propagation," Proc. IRE, Vol. 41, pp. 146-152, January, 1953.

APPENDIX I

CALCULATION OF THE ANGULAR DISTANCE, θ, OVER IRREGULAR TERRAIN

We see by Fig. 2e that the angular distance $\theta = \alpha_o + \beta_o$ is simply equal, over a smooth spherical earth, to the distance between the horizons of the transmitting and receiving antennas divided by the effective radius of the earth, a:-*

$$\theta = \frac{d - d_{Lt} - d_{Lr}}{a} \tag{1}$$

Fig. I-1 shows the geometry involved to take into account the effect of irregular terrain on the determination of α_o; a similar geometry is involved in the determination of β_o.

From this geometry it may be shown that:-

$$\alpha_o = \frac{d}{2a} - \frac{d_{Lt}}{a} + \frac{(h_{ts} - h_{rs})}{d} - \delta_t \tag{2}$$

$$\beta_o = \frac{d}{2a} - \frac{d_{Lr}}{a} - \frac{(h_{ts} - h_{rs})}{d} - \delta_r \tag{3}$$

where

$$\delta_t = \frac{h_{ts} - h_{Lt} - \frac{d_{Lt}^2}{2a}}{d_{Lt}} \tag{4}$$

$$\delta_r = \frac{h_{rs} - h_{Lr} - \frac{d_{Lr}^2}{2a}}{d_{Lr}} \tag{5}$$

$$\theta \equiv \alpha_o + \beta_o = \frac{d - d_{Lt} - d_{Lr}}{a} - \delta_t - \delta_r \tag{6}$$

In the above d_{Lt} and d_{Lr} denote the actual distances to the radio horizons as determined from the terrain profiles plotted for the path, h_{Lt} and h_{Lr} denote the heights above sea level of the terrain at the respective horizons, and h_{ts} and h_{tr} denote the antenna heights above the same reference, sea level. The distance to the radio horizon, d_{Lt}, is determined by plotting on linear graph paper the heights, $h_T(x)$, above sea level of the actual terrain at the distances, x, corrected for the effects of the normal earth's curvature and of air refraction, $\left[h_T(x) - \frac{x^2}{2a}\right]$, versus the distance. The farthest unobstructed point on the terrain, as determined on this modified plot, is the radio horizon, and the distance to this point is denoted by d_{Lt}; this is the same procedure as that used by Norton1/ in a recent paper.

*The symbol a is used for simplicity to denote ka', where a' denotes the actual radius of the earth.

1/ Kenneth A. Norton, "Transmission Loss of Space Waves Propagated Over Irregular Terrain," Trans. of IRE Professional Group on Antennas and Propagation, No. PGAP-3, August, 1952; Also published as NBS Report 1737, June 16, 1952.

GEOMETRY FOR IRREGULAR TERRAIN CALCULATIONS

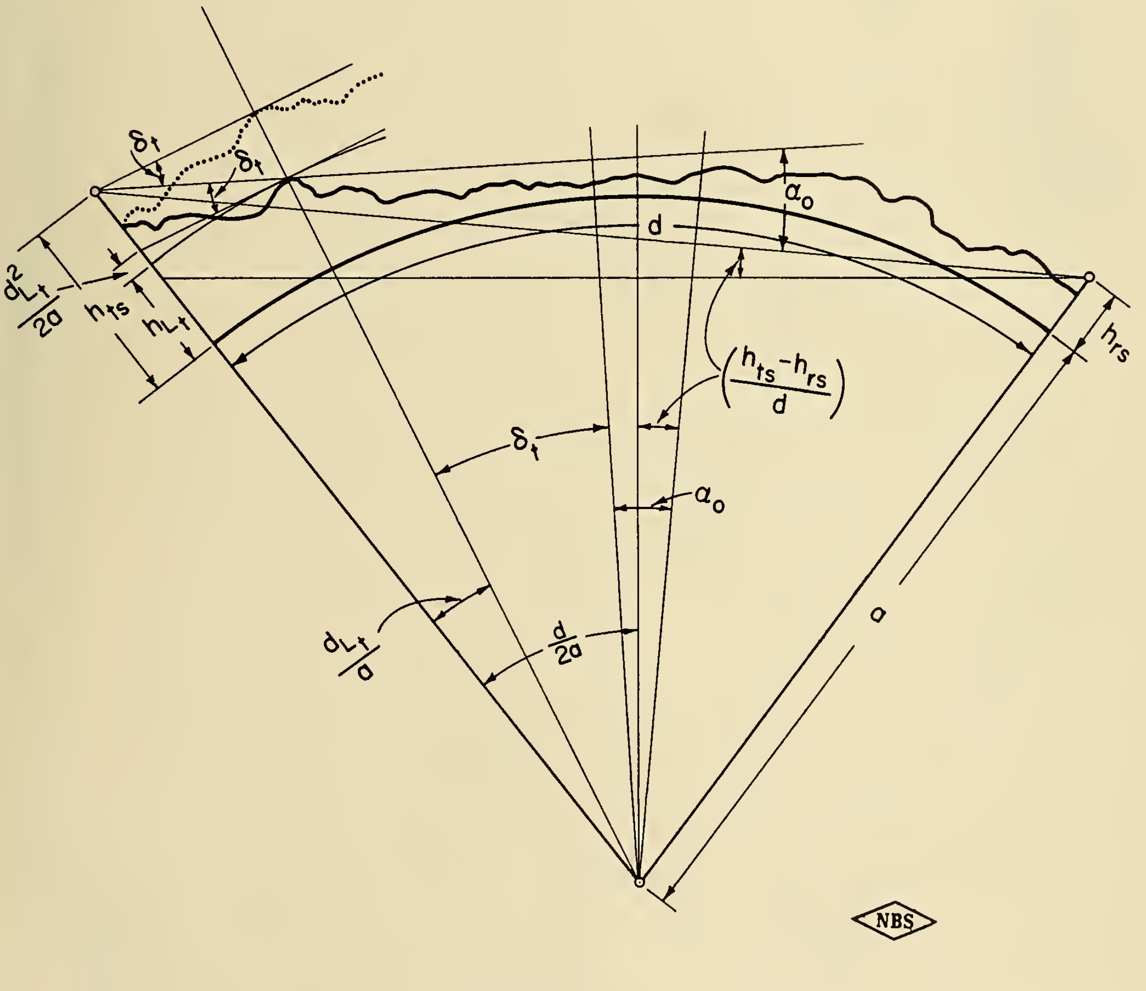
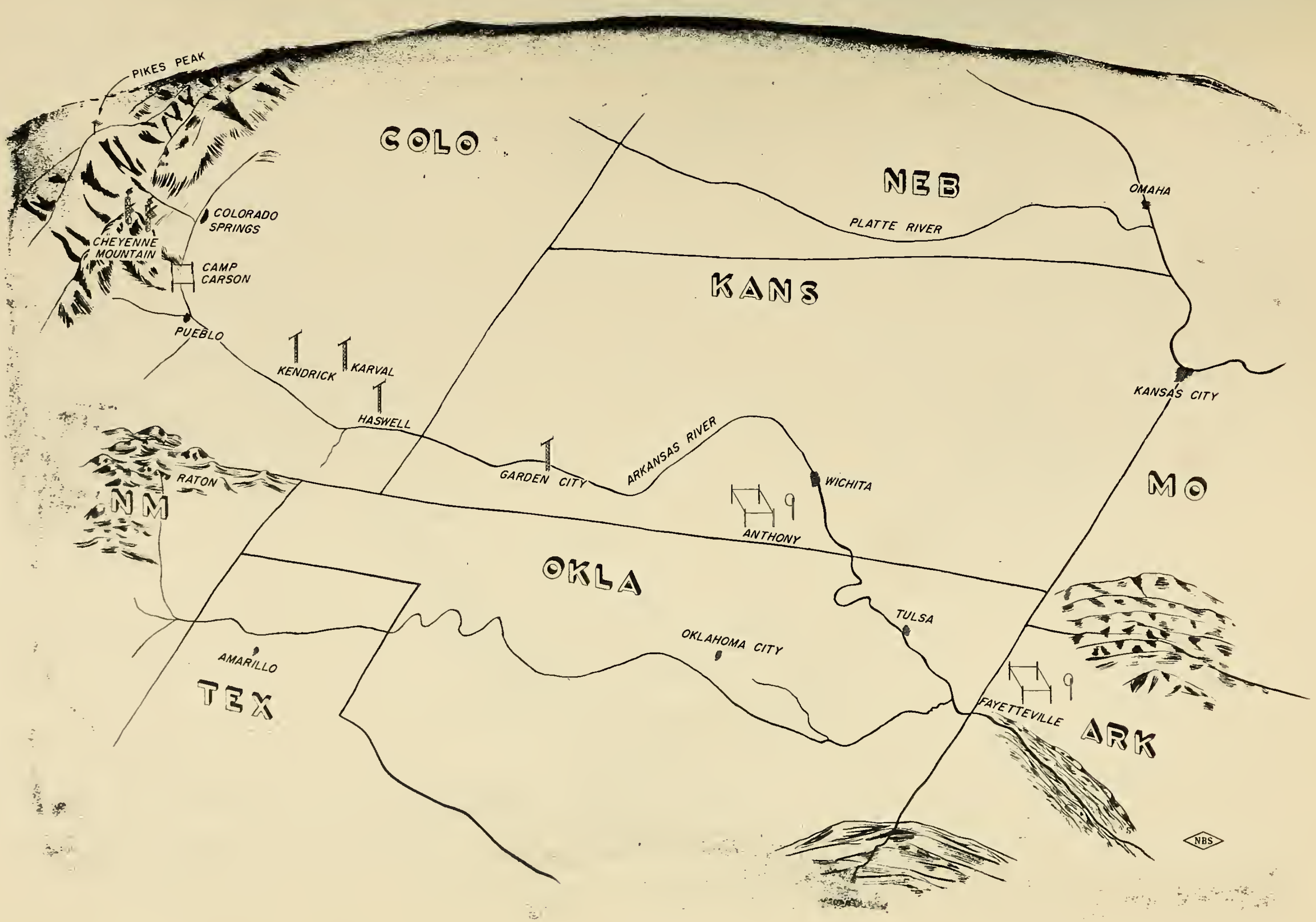


Figure I-1



PIKES PEAK
COLO
NEB
OMAHA
COLORADO SPRINGS
PLATTE RIVER
CHEYENNE MOUNTAIN
CAMP CARSON
KANS
PUEBLO
KENDRICK
KARVAL
KANSAS CITY
HASWELL
ARKANSAS RIVER
RATON
GARDEN CITY
WICHITA
MO
NM
ANTHONY
OKLA
TULSA
OKLAHOMA CITY
AMARILLO
FAYETTEVILLE
TEX
ARK
NBS

FIG. 1

TERRAIN PROFILE OF COLORADO-KANSAS PATHS

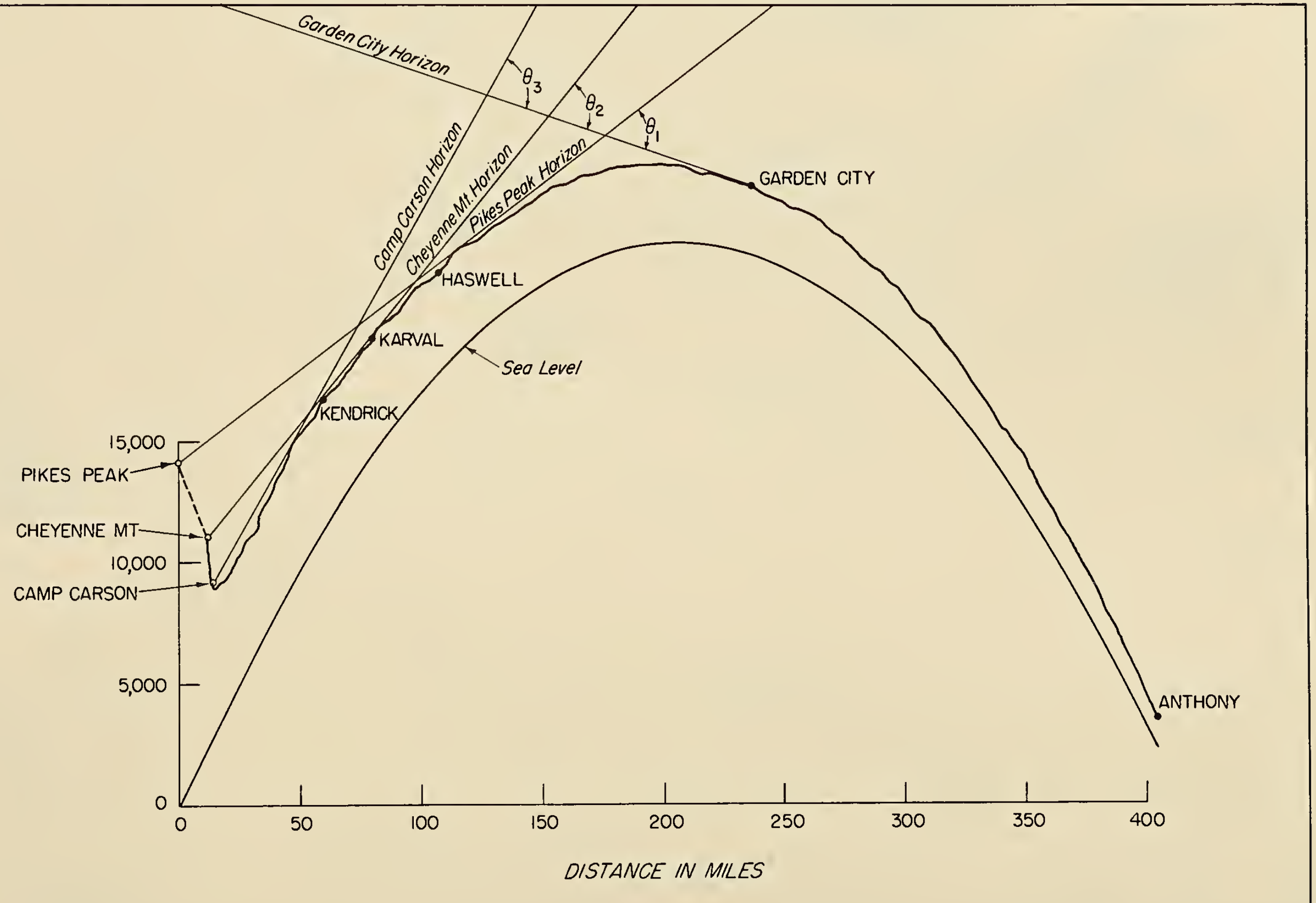


Figure 2d

THE PARAMETER θ IN TROPOSPHERIC WAVE PROPAGATION

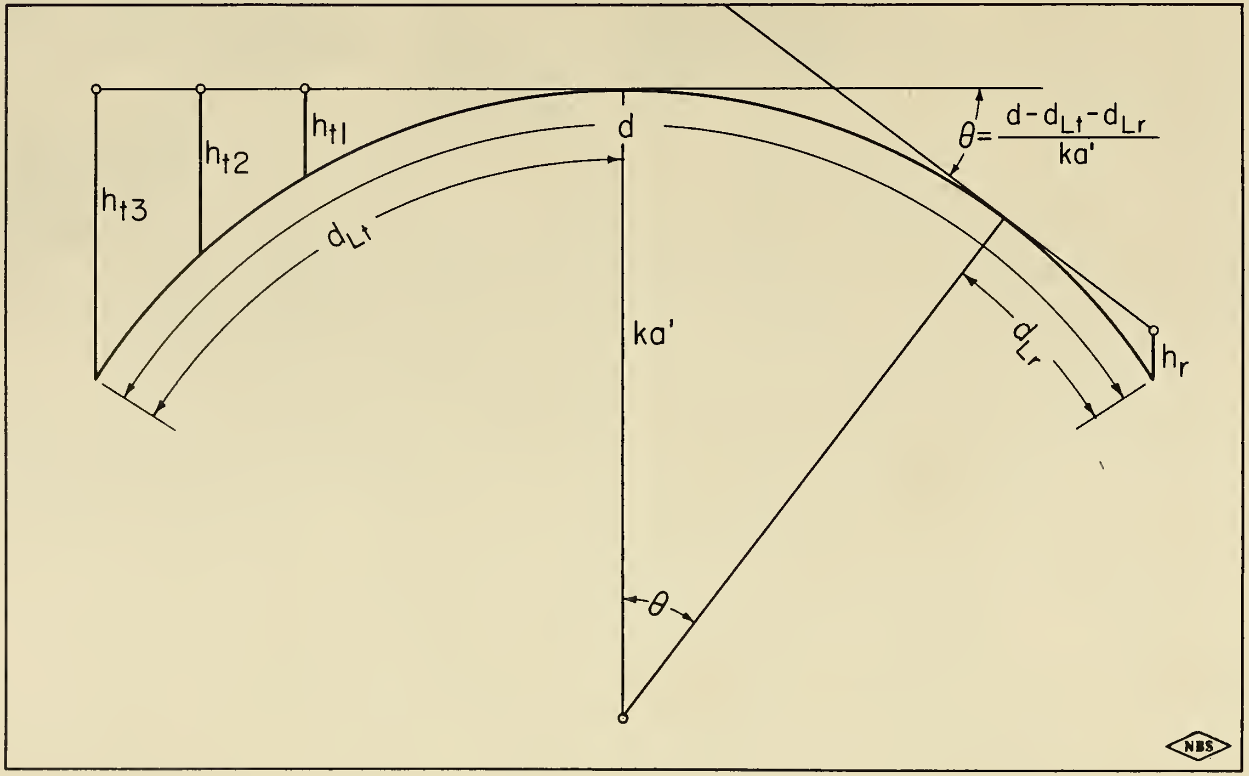


Figure 2e

Figure 3a

BLOCK DIAGRAM OF 5 KW 1046 MC TRANSMITTER

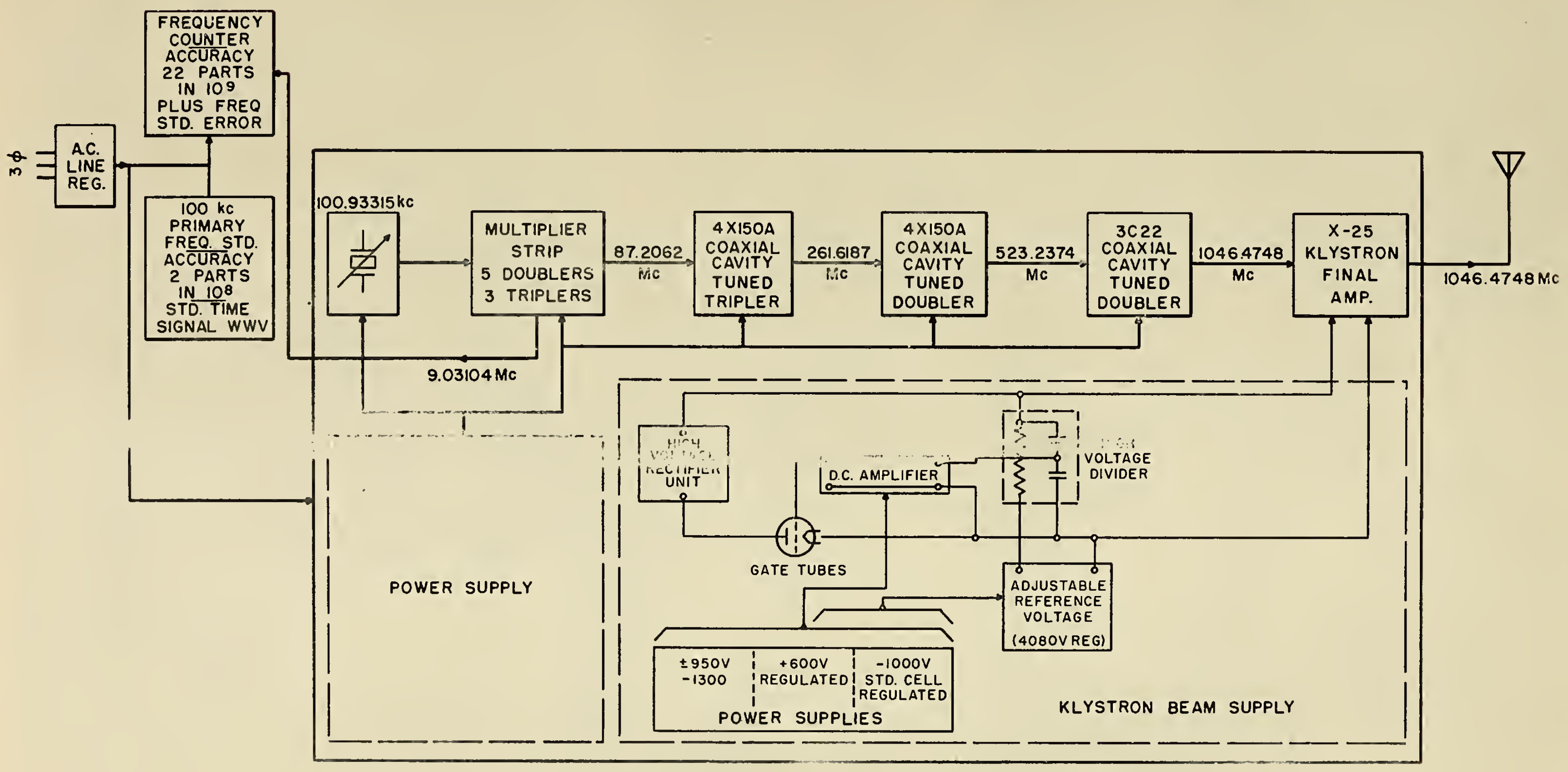


Figure 3d

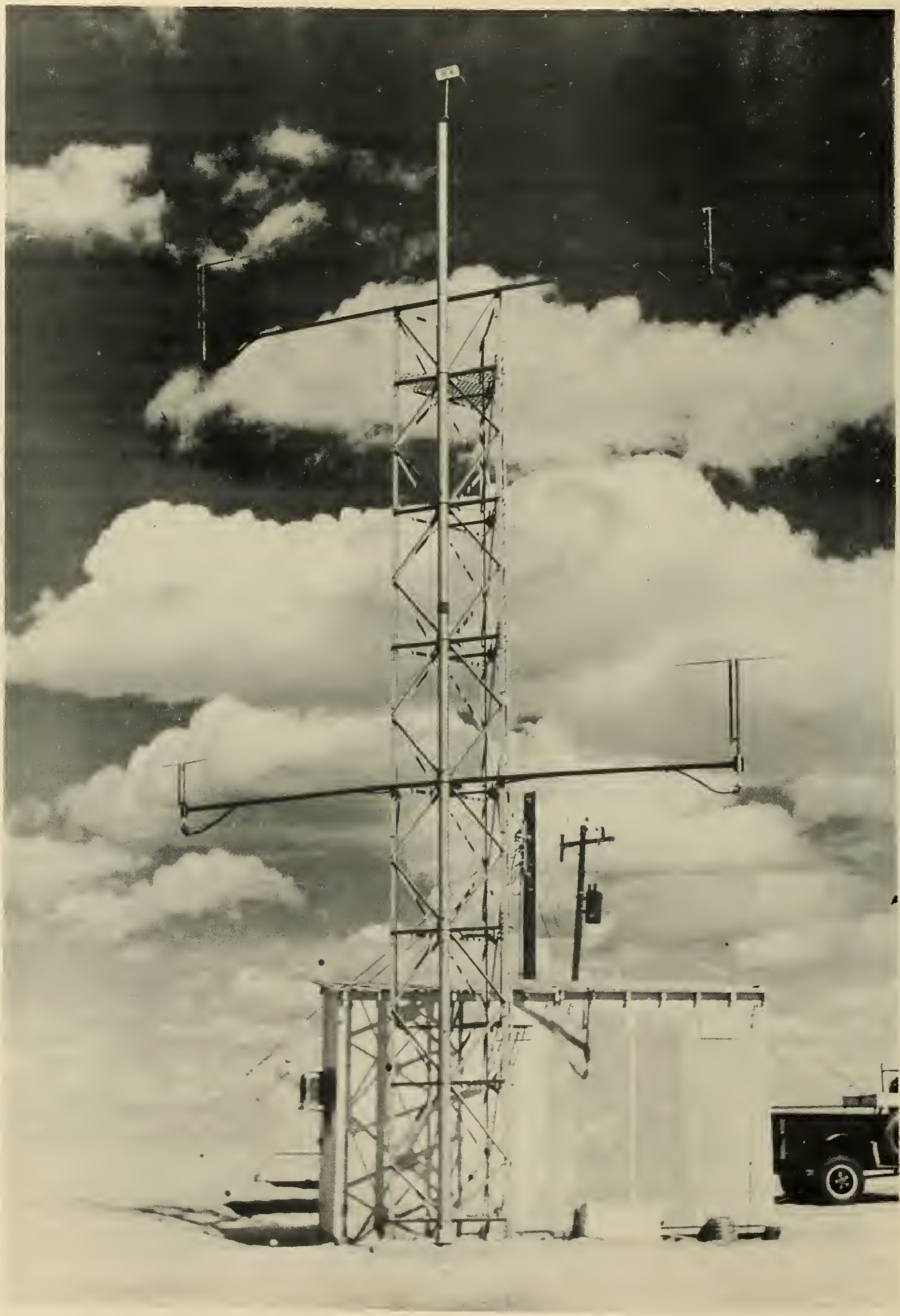


Figure 4a

Figure 4b

SAMPLE 1046 Mc RECORDINGS
MDNT - 6AM, FEBRUARY 23, 1952

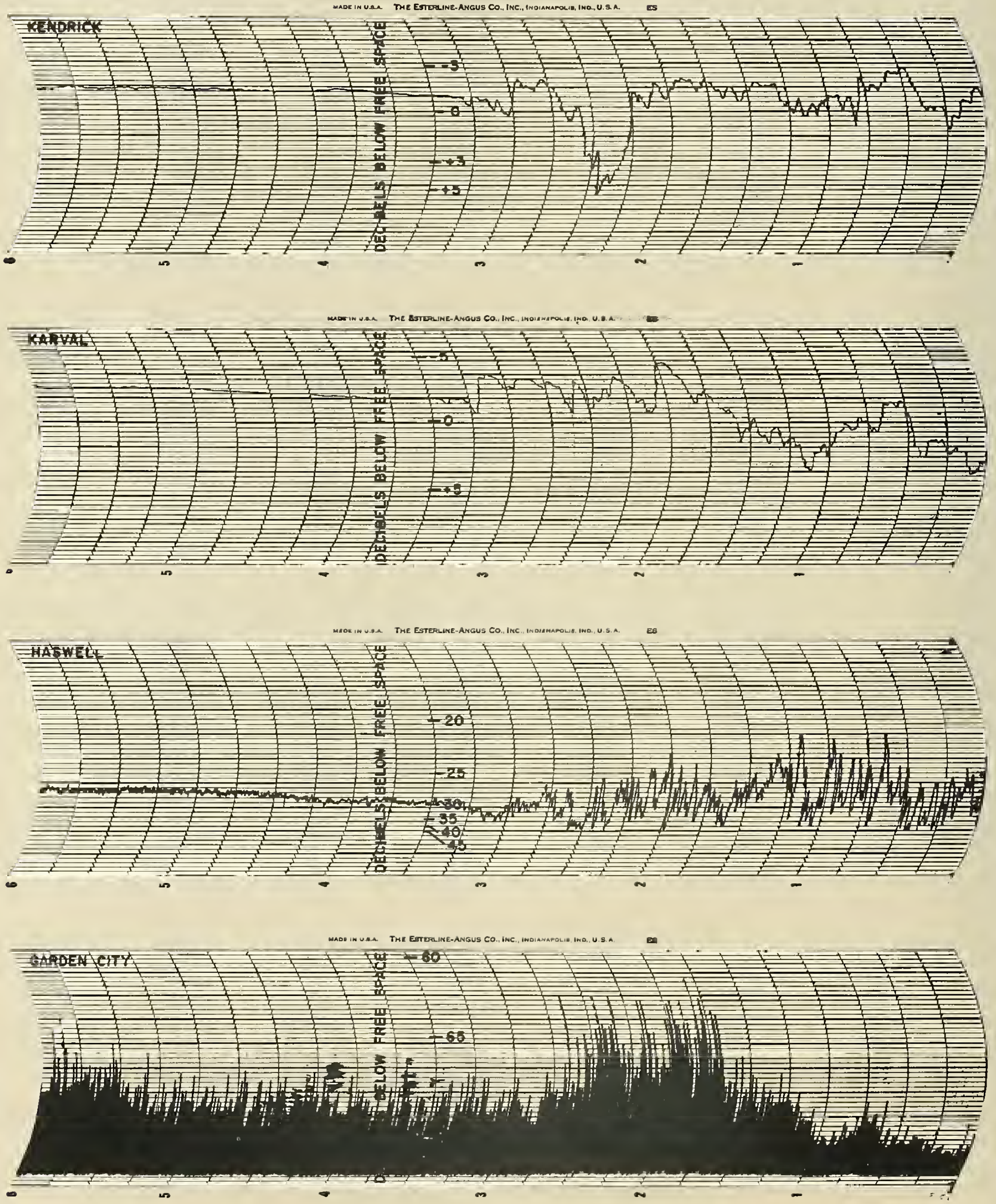


FIG. 5a

DISTRIBUTIONS OF HOURLY MEDIAN SIGNAL LEVELS
RECORDED ON 1046 Mc FEB. 1952 - JAN. 1953

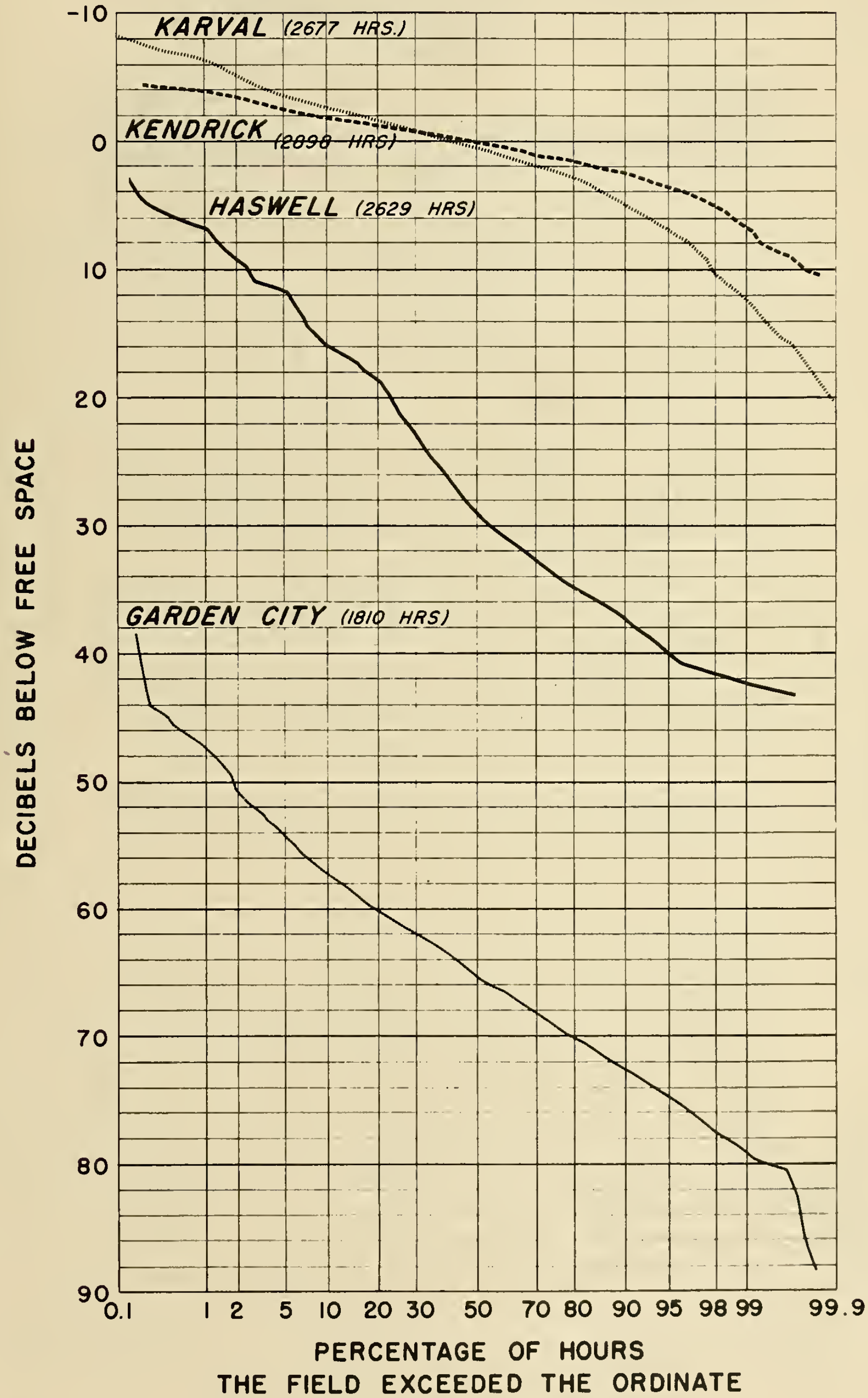


FIG. 6k

DIURNAL VARIATION OF DIFFERENCE IN DECIBELS OF LEVELS EXCEEDED BY 10% AND 90% OF ALL HOURLY MEDIANS

1046 Mc

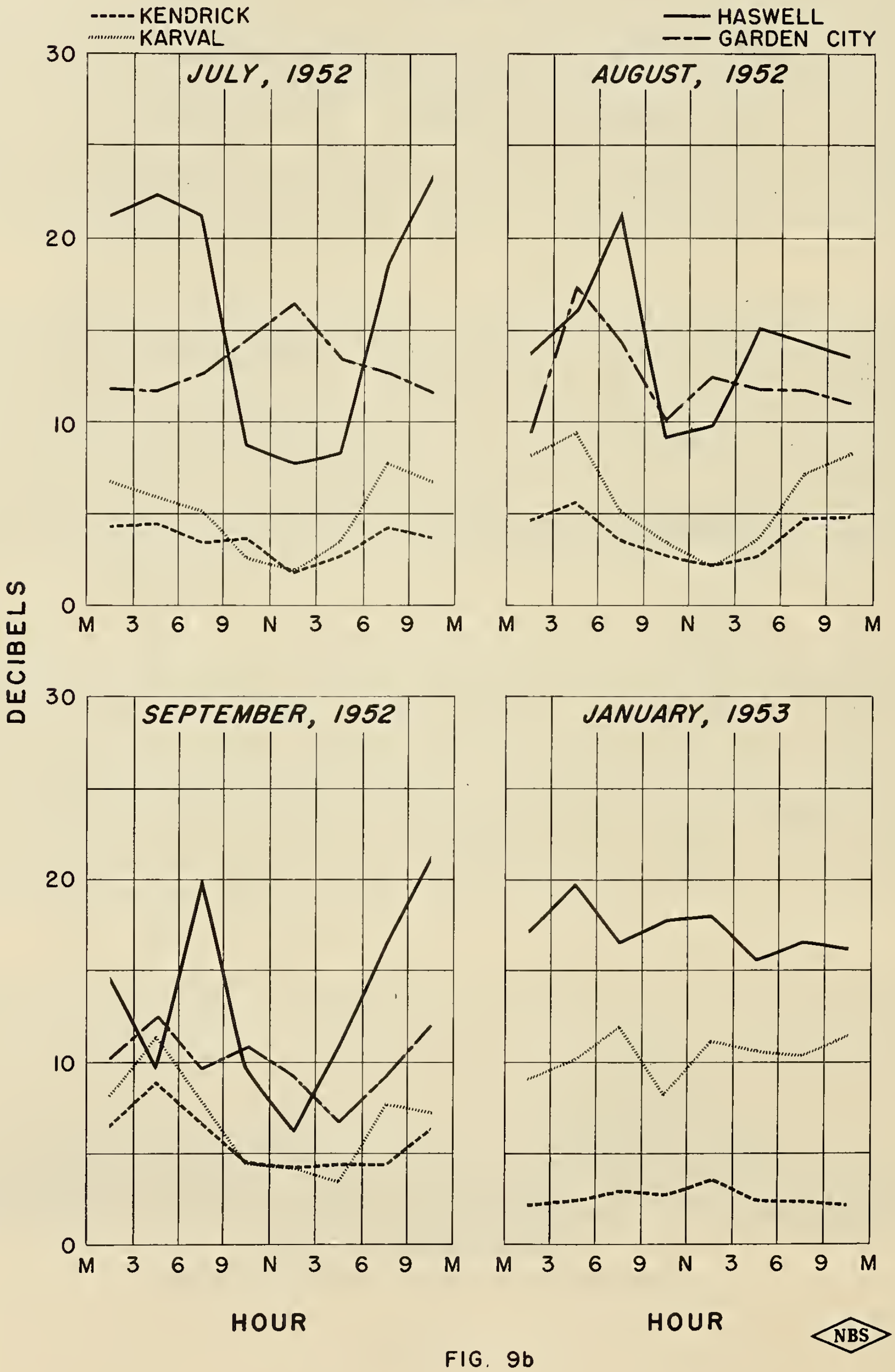


FIG. 9b

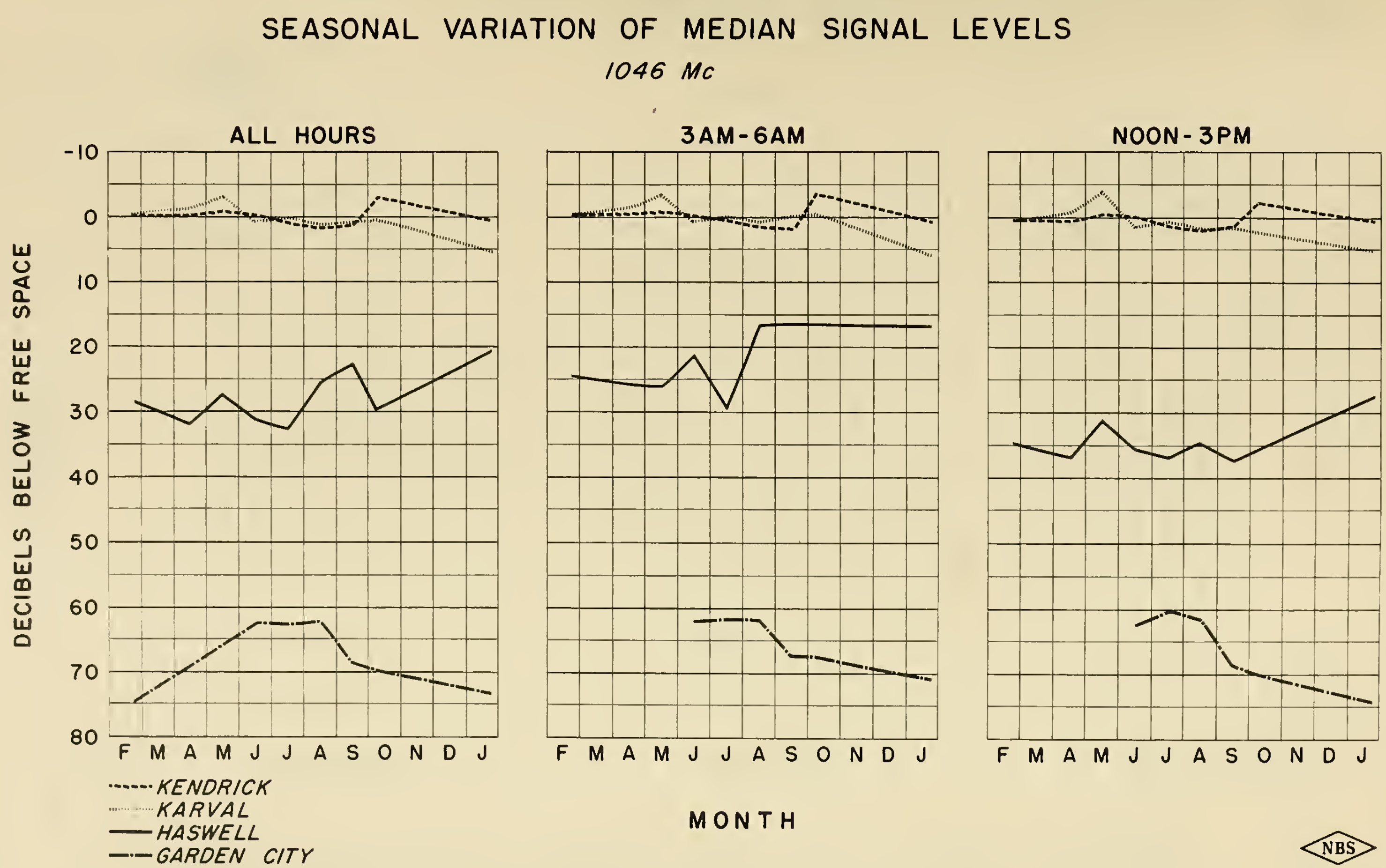

SEASONAL VARIATION OF MEDIAN SIGNAL LEVELS
1046 Mc
ALL HOURS
3AM-6AM
NOON-3PM
DECIBELS BELOW FREE SPACE
-10
0
10
20
30
40
50
60
70
80
F M A M J J A S O N D J
KENDRICK
KARVAL
HASWELL
GARDEN CITY
MONTH

FIG. 10a

SEASONAL VARIATION OF DIFFERENCE IN DECIBELS
OF LEVELS EXCEEDED BY 10% AND 90% OF ALL HOURLY MEDIANS

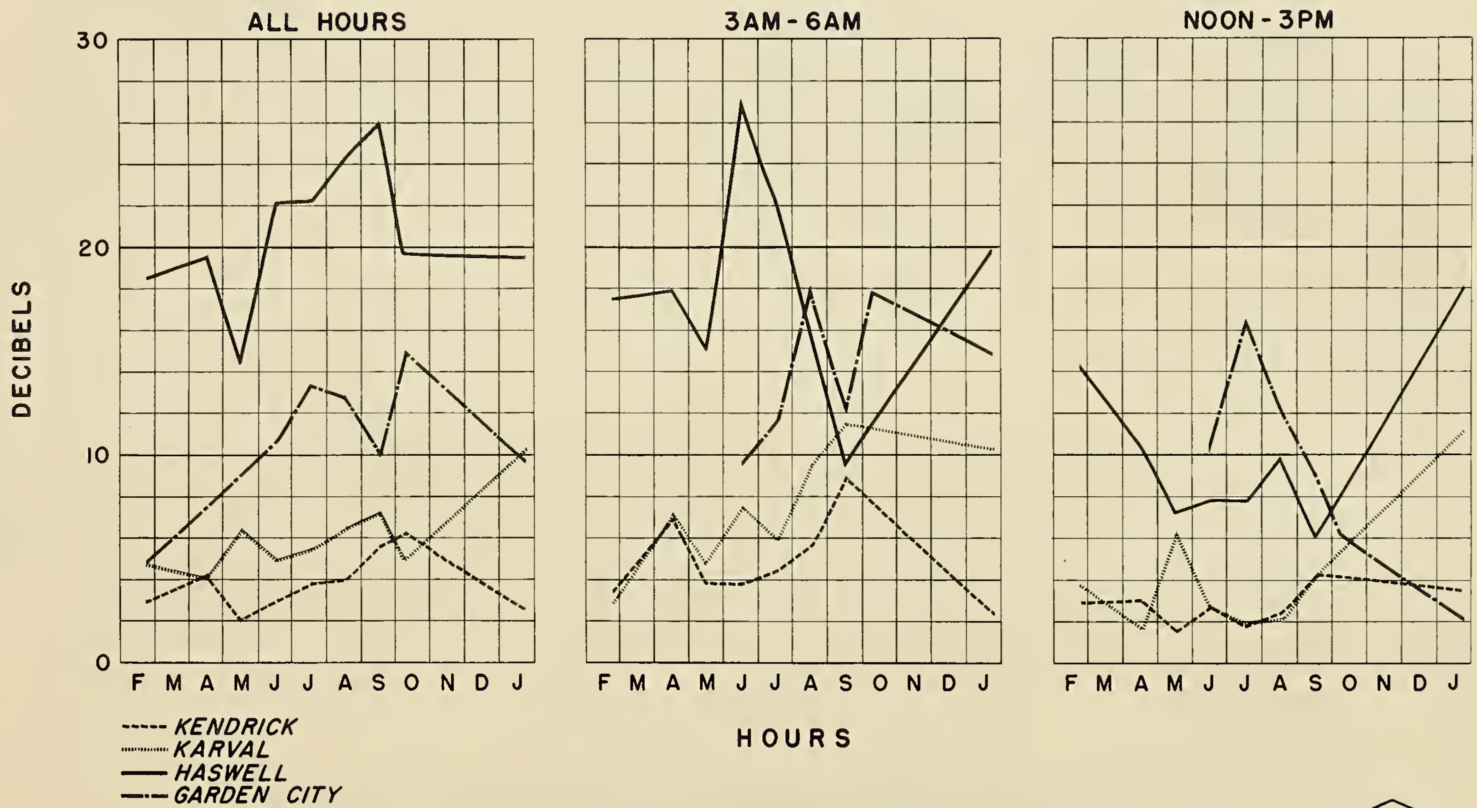


FIG. 10b

DISTRIBUTION OF MONTHLY MEDIAN SIGNAL LEVELS VERSUS DISTANCE

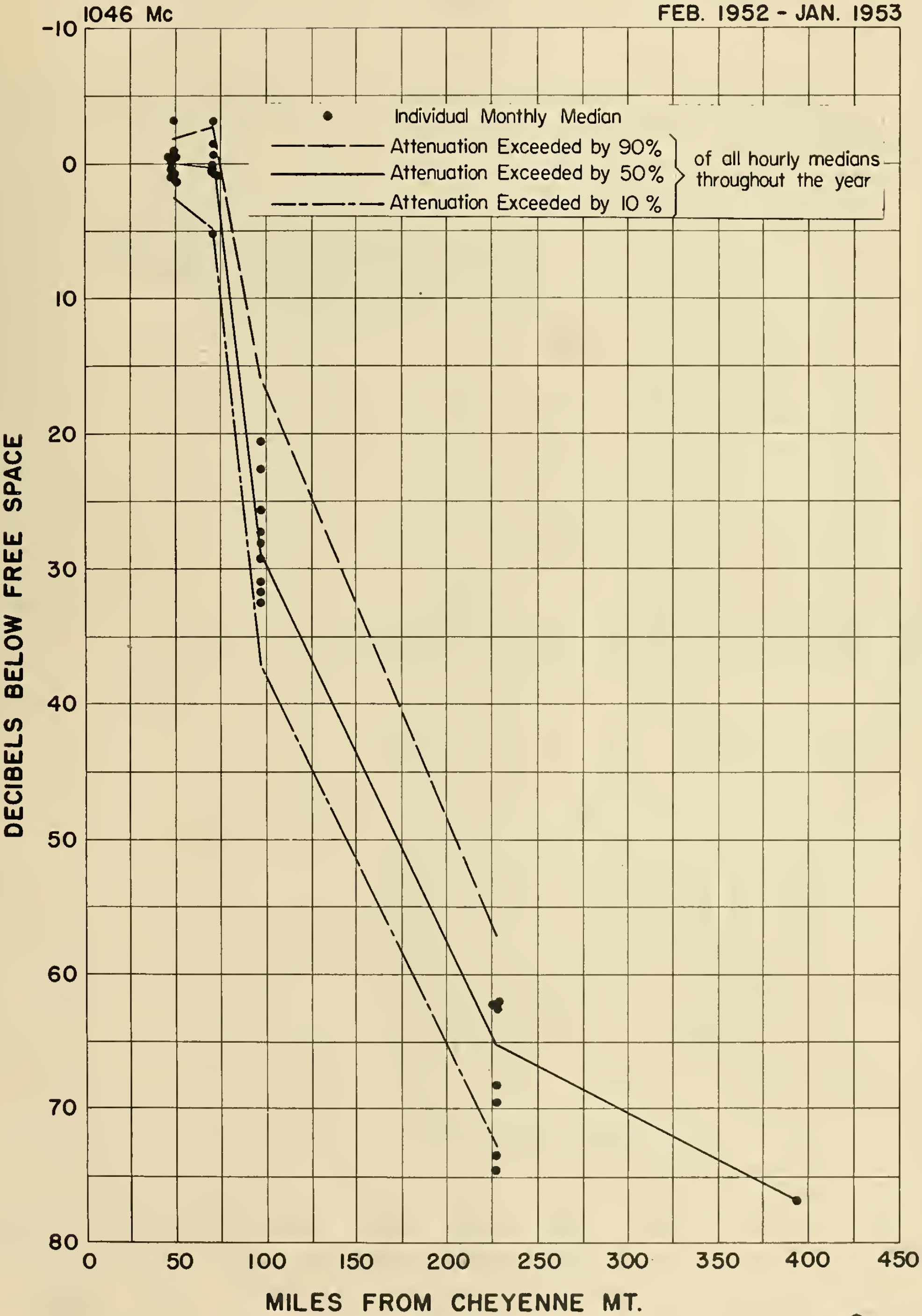


FIG. 11a

DISTRIBUTION OF MONTHLY RATIOS OF LEVELS EXCEEDED BY 10% AND 90% OF ALL HOURLY MEDIANS VERSUS DISTANCE

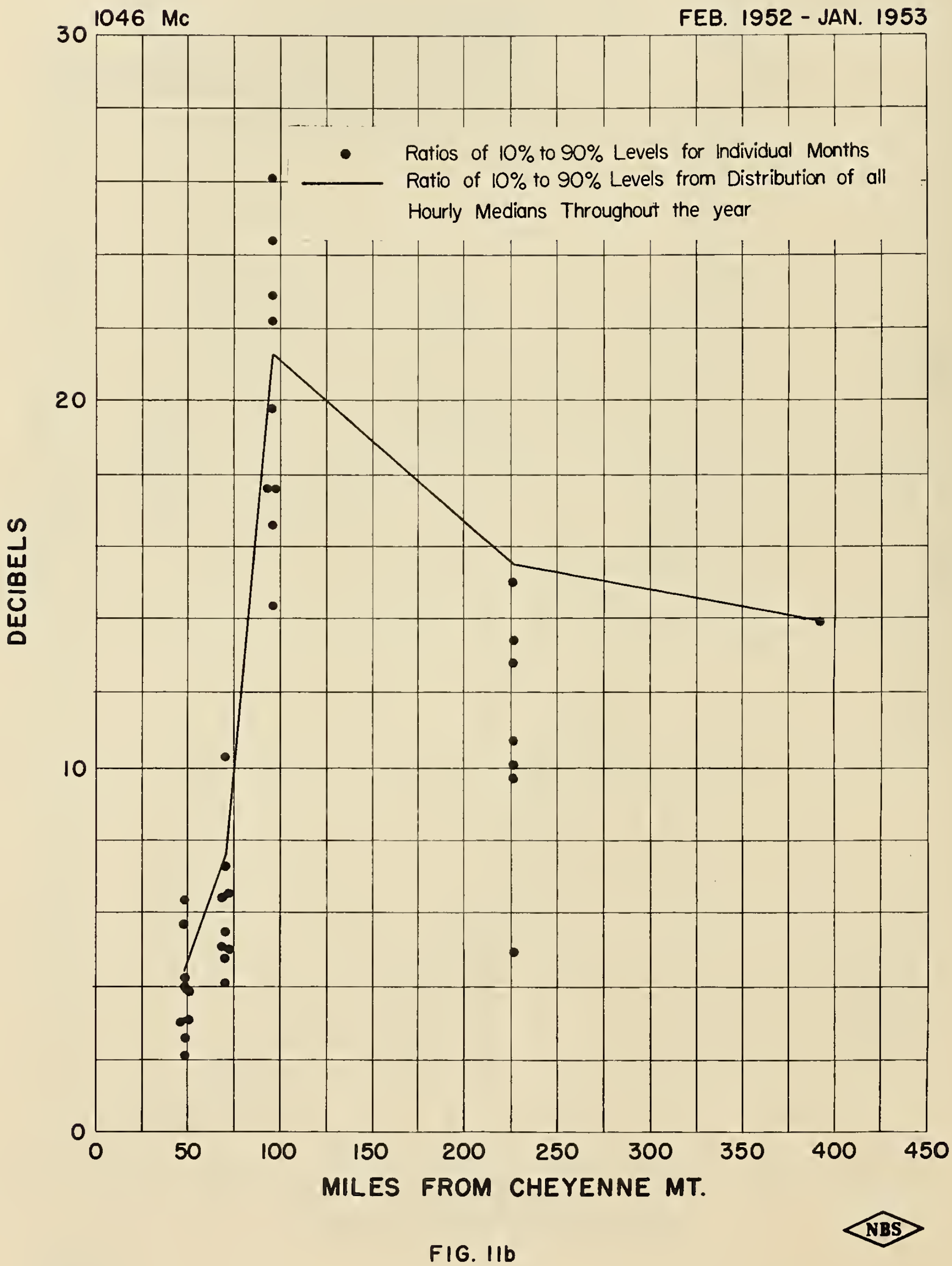


FIG. 11b

DEPENDENCE OF ATTENUATION RELATIVE TO FREE SPACE ON THE ANGULAR DISTANCE BELOW THE HORIZON

θ Calculated Assuming k = 4/3

August, 1952 Data

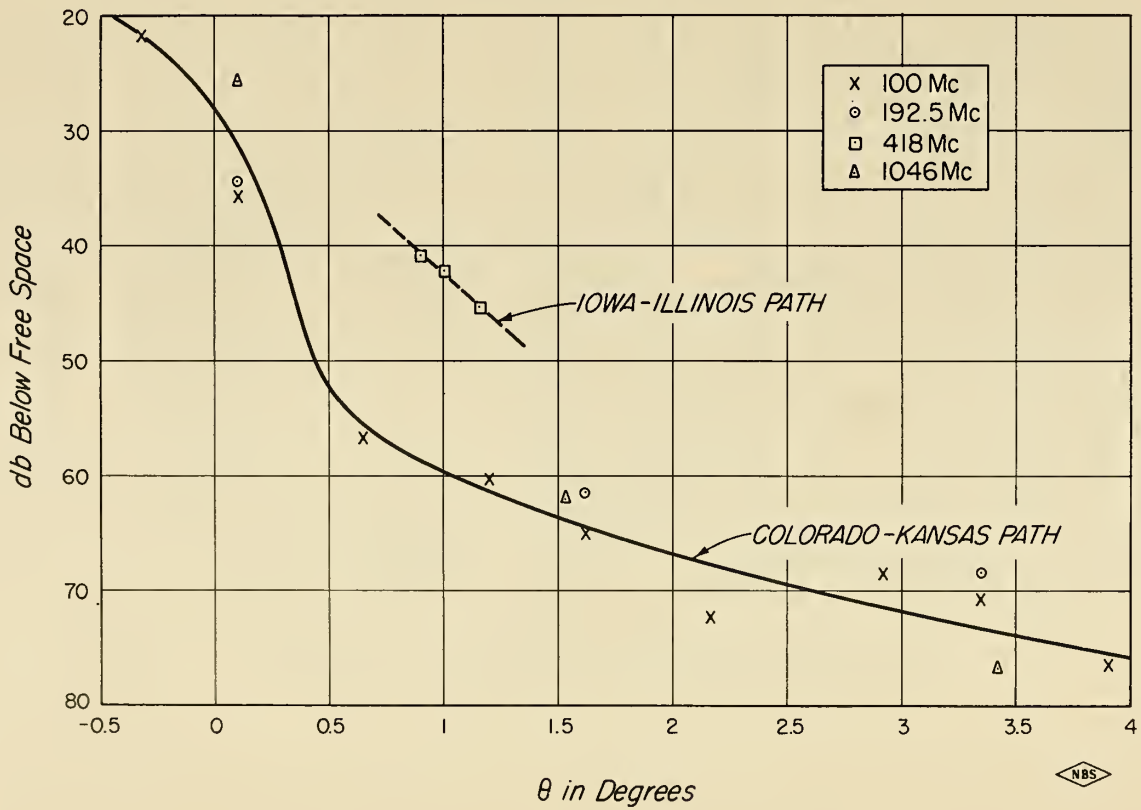


Figure 11c

AVERAGE DISTRIBUTIONS OF INSTANTANEOUS SIGNAL LEVELS

1046 Mc; August 1952

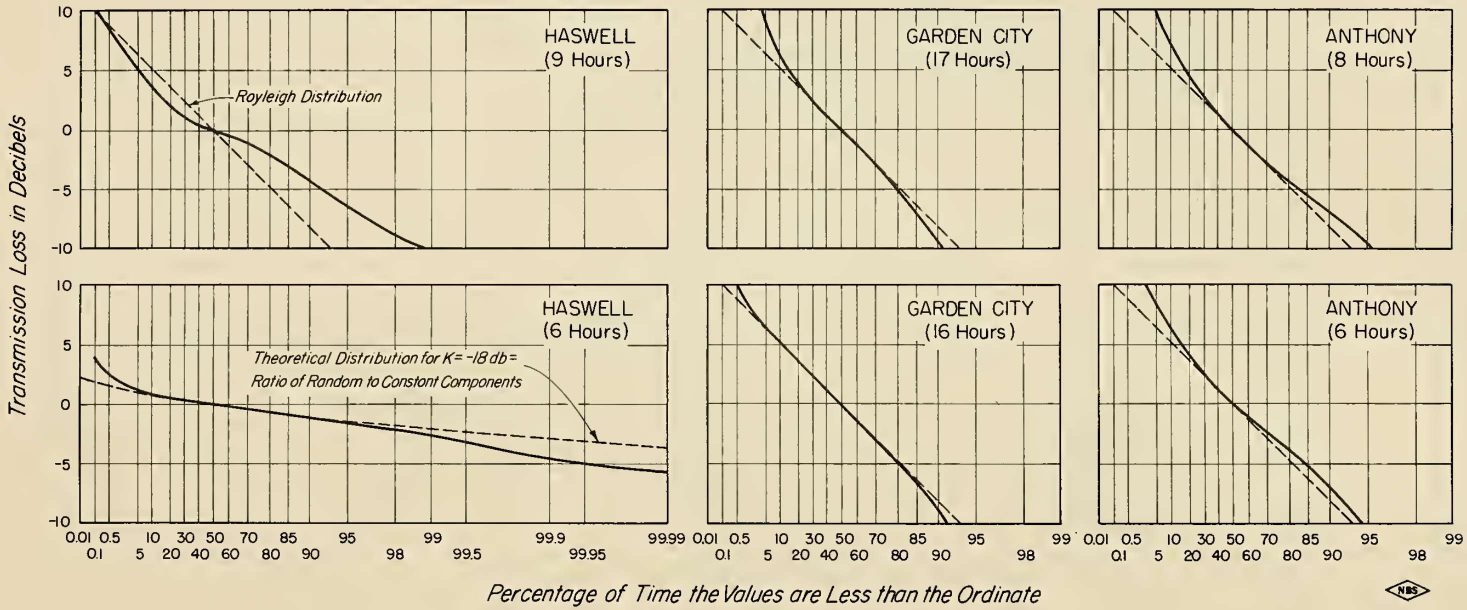


Figure 12a

DIURNAL VARIATION OF HOURLY MEDIANS AND OF FADING RANGE

1046 Mc; Haswell, Colorado; August 1952

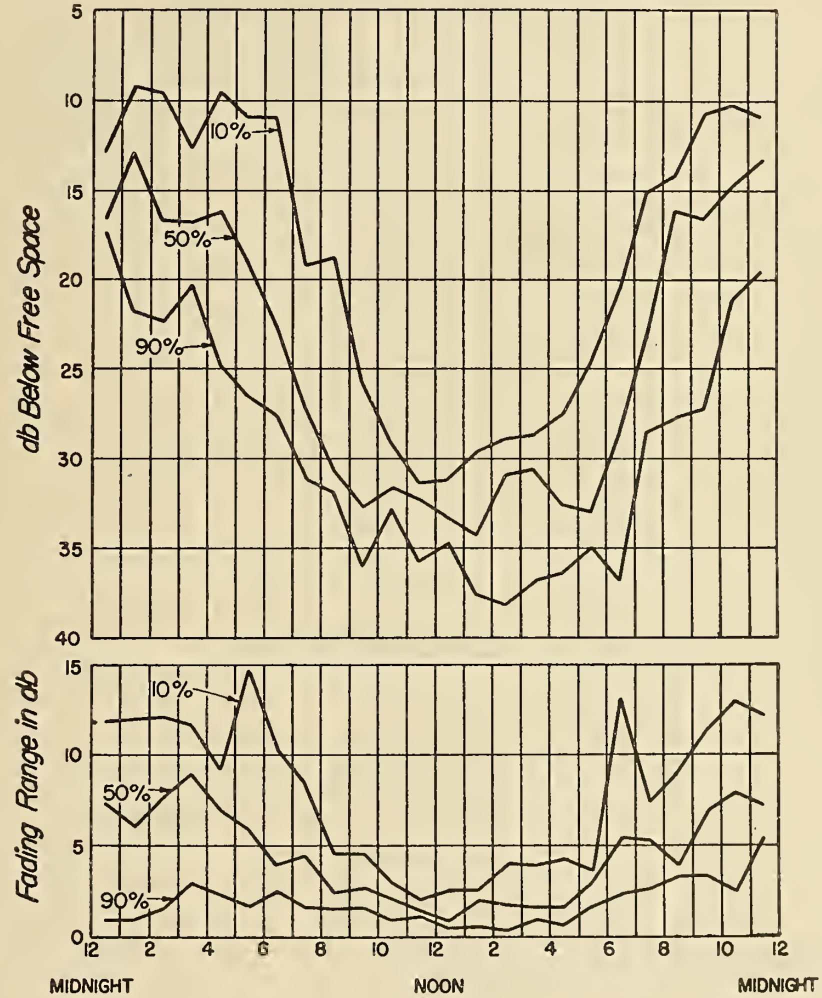


Figure 12 b

DEPENDENCE OF FADING RANGE
ON THE ANGULAR DISTANCE BELOW THE HORIZON

θ Calculated Assuming $k=4/3$

August, 1952 Data

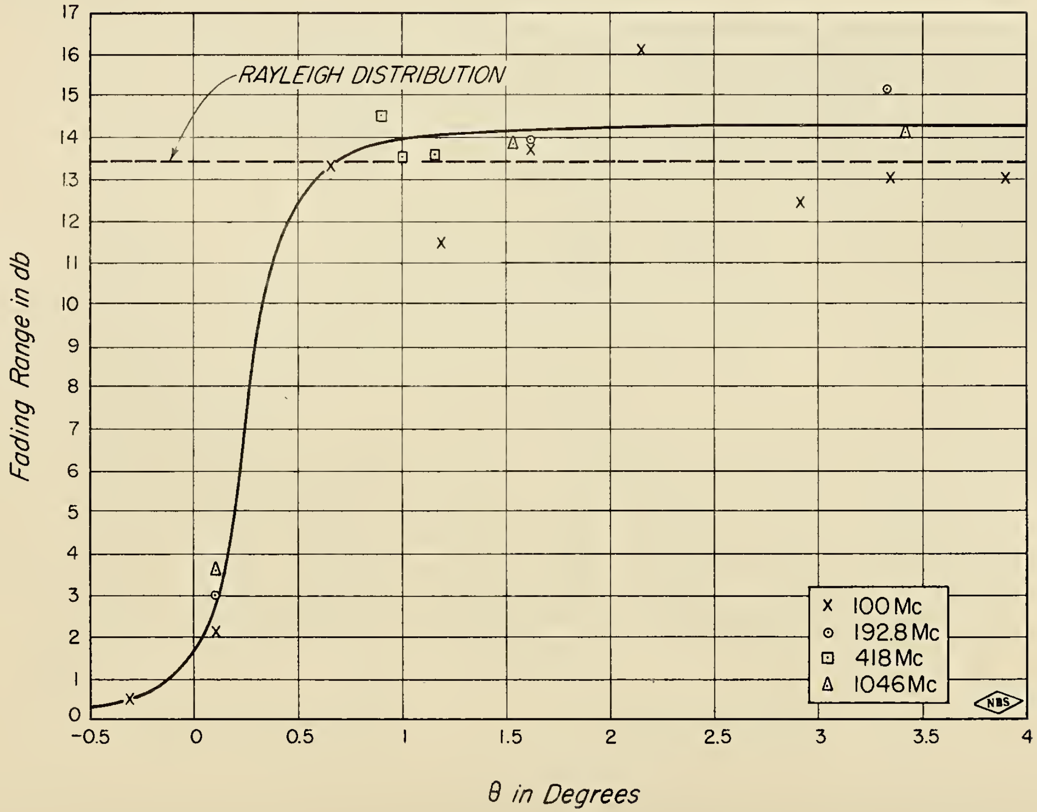
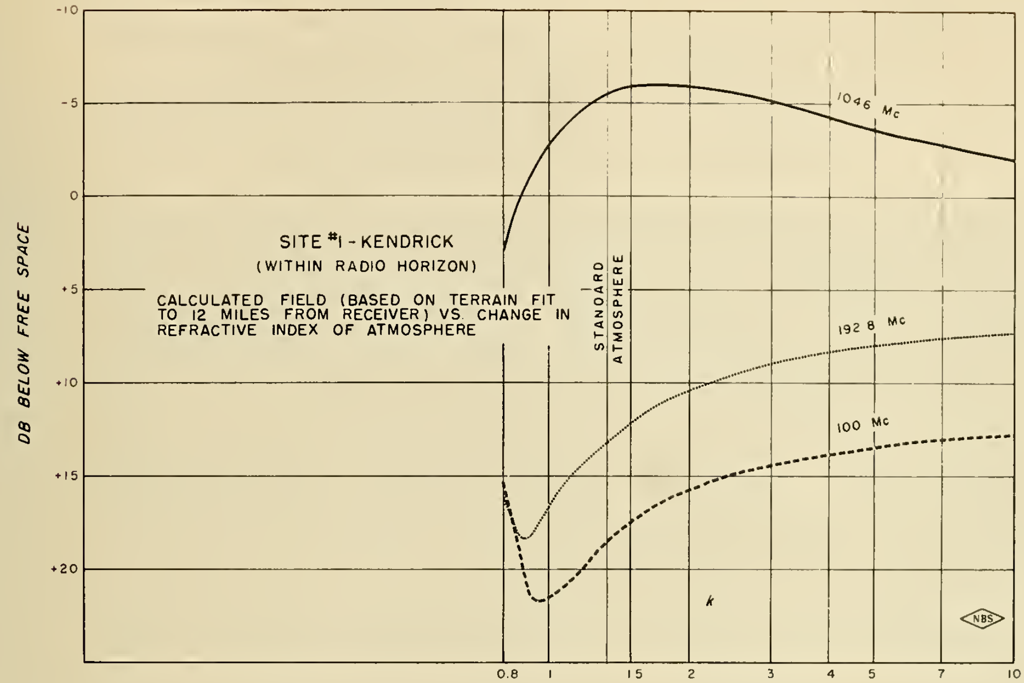


Figure 12e



$$\frac{1}{ka} = \frac{1}{a} + \frac{1}{n_a}\frac{dn}{dh}$$

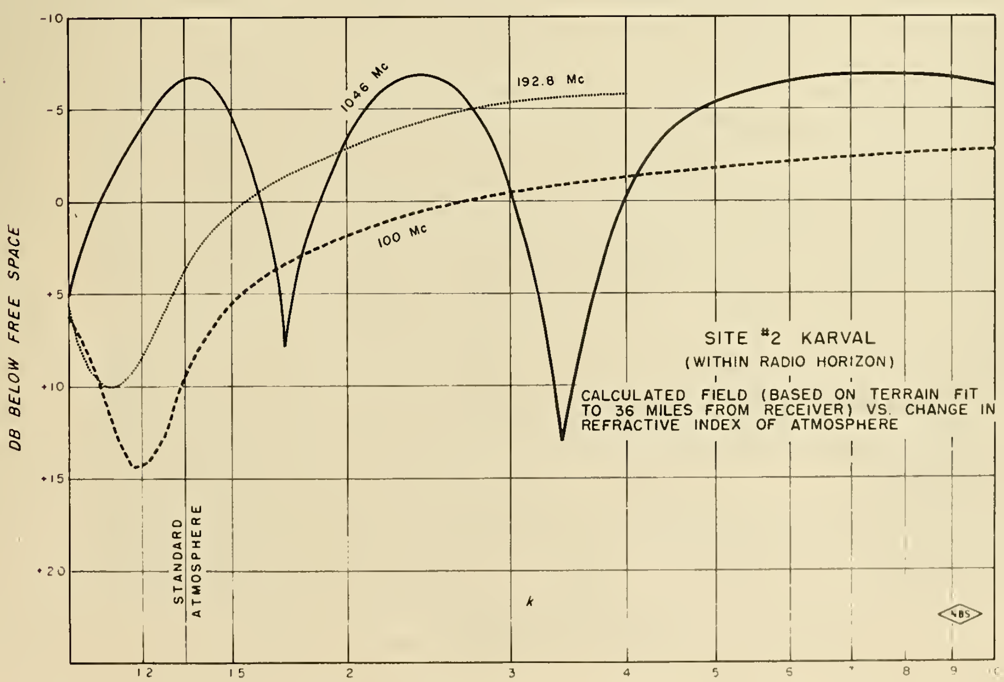


FIG [illegible]

CHEYENNE MOUNTAIN OPTICAL PATHS

PLOT OF FIELD DEVIATIONS VS. RAYLEIGH'S CRITERION

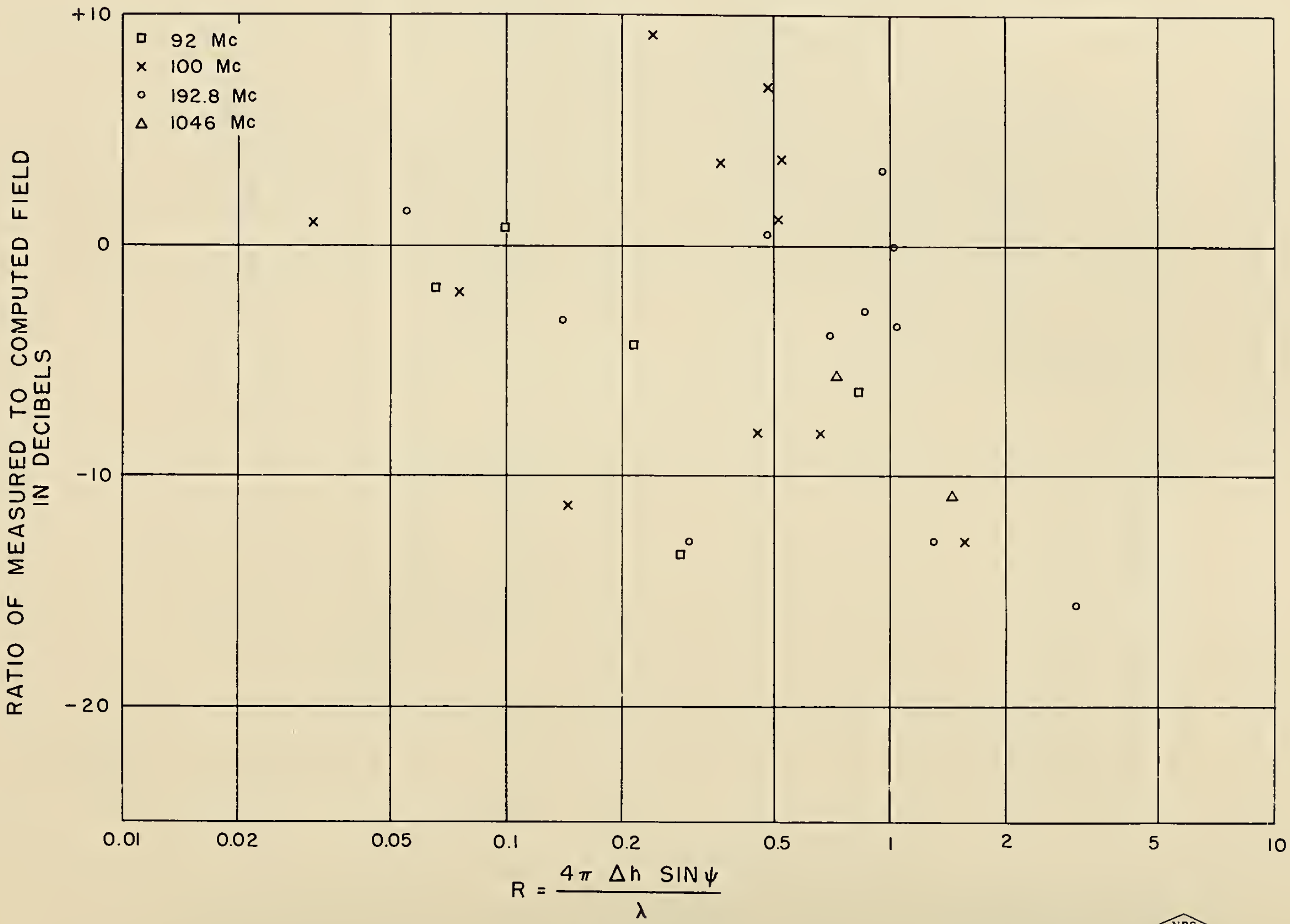
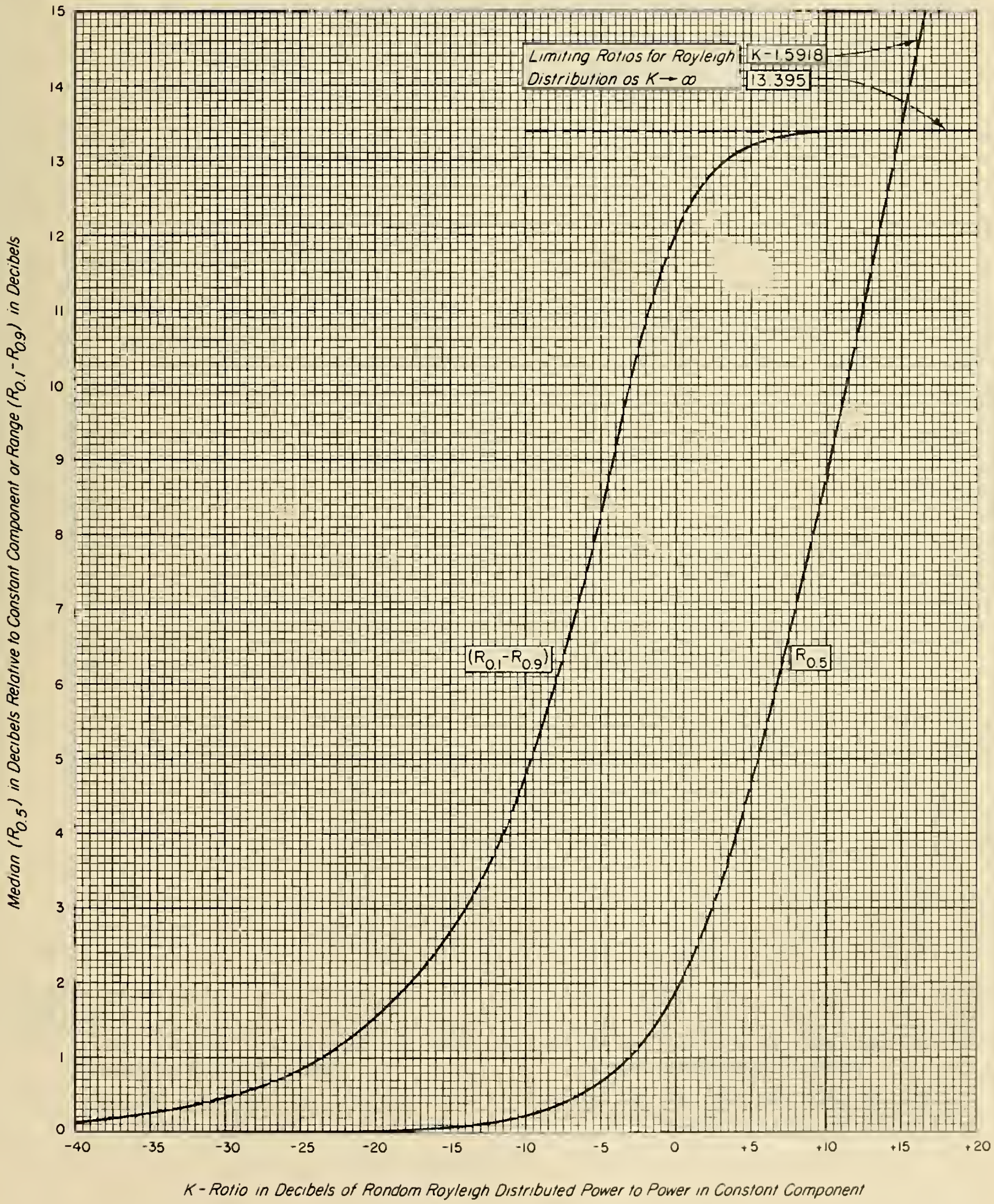


FIG. 14b

MEDIAN ($R_{0.5}$) AND RANGE ($R_{0.1}-R_{0.9}$) FROM THE CUMULATIVE DISTRIBUTION OF THE RESULTANT AMPLITUDE OF A CONSTANT VECTOR PLUS A RAYLEIGH DISTRIBUTED VECTOR

Power in Random Component is ($K-R_{0.5}$) Decibels Relative to the Median Level of the Cumulative Distribution



NBS

Figure 15a

CORRELATION OF CHEYENNE MOUNTAIN FIELD STRENGTHS RECEIVED ON SPACED ANTENNAS AT GARDEN CITY, KANSAS

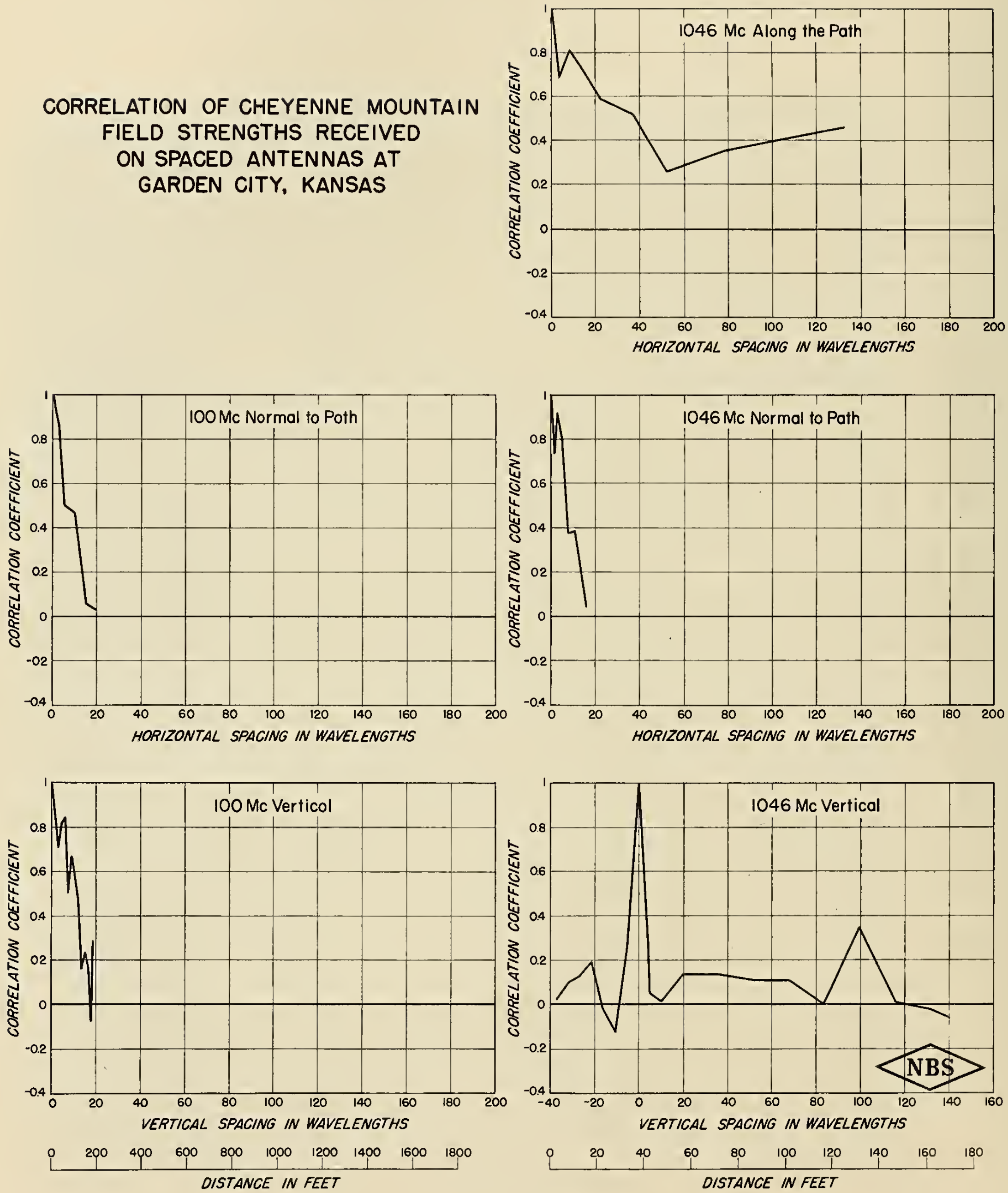


Figure 15b

HEIGHT GAIN OBSERVATIONS AT GARDEN CITY, KANSAS

Ratios of Median Fields Observed During 1 to 10 Minute Periods
On Vertically Spaced Antennas

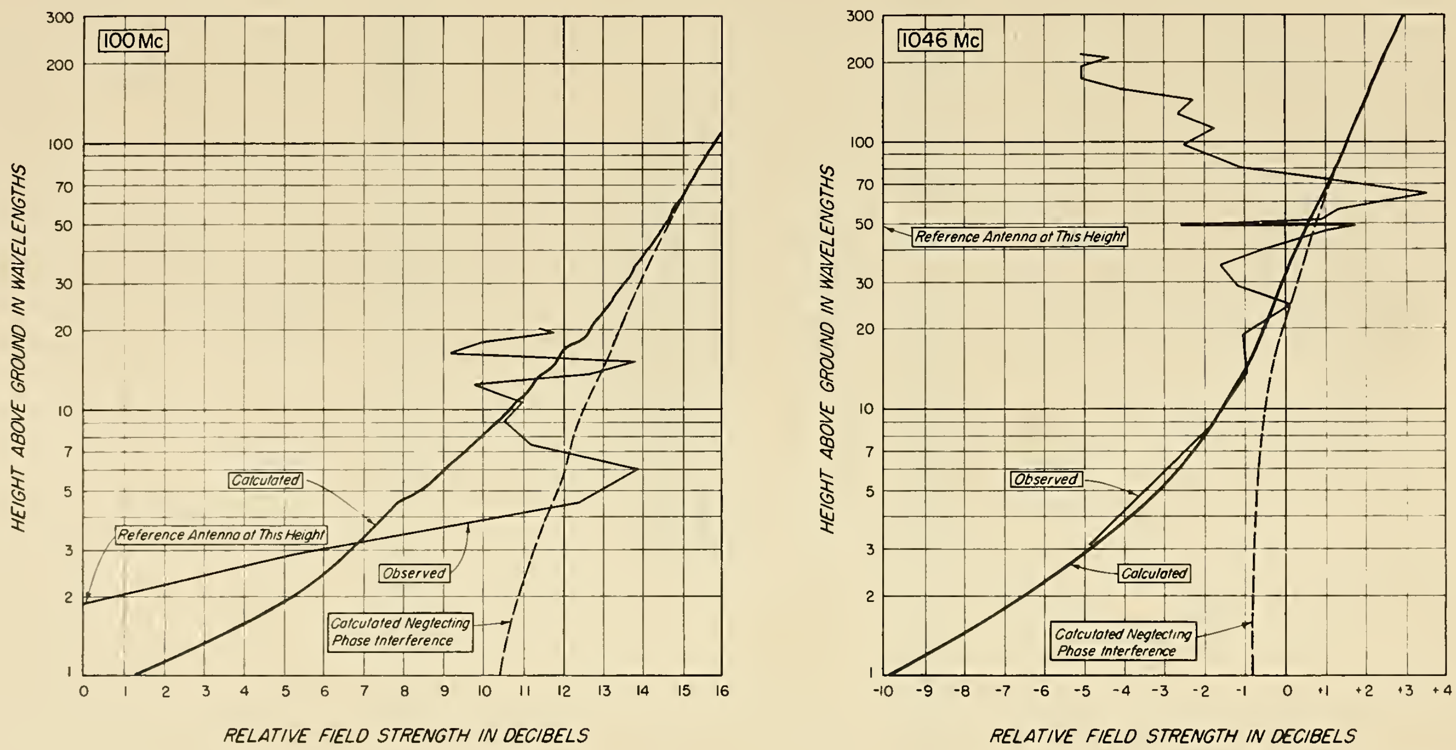


Figure 15d

Supplement VII

THE RATE OF FADING IN TROPOSPHERIC PROPAGATION

By

K. A. Norton and H. B. Janes
National Bureau of Standards
Boulder, Colorado

See No. 324, page 112f in the list of technical abstracts.

Supplement VIII

RADIO TRANSMISSION LOSS VERSUS DISTANCE AND ANTENNA HEIGHT AT 100 Mc

By

P. L. Rice and F. T. Daniel
National Bureau of Standards
Boulder, Colorado

Published in Trans. IRE, Professional Group on Antennas and Propagation, Vol. AP-3, No. 2, pp. 59-62, April, 1955.

See No. 35, pp. 20, in list of technical abstracts.

Supplement IX

RADIO TRANSMISSION LOSS VERSUS ANGULAR DISTANCE AND ANTENNA HEIGHT AT 100 Mc

By

P. L. Rice, F. T. Daniel, W. V. Mansfield, and P. J. Short

Supplement IX

RADIO TRANSMISSION LOSS VERSUS ANGULAR DISTANCE AND ANTENNA HEIGHT AT 100 MEGACYCLES

By

P. L. Rice, F. T. Daniel, W. V. Mansfield, P. J. Short
National Bureau of Standards
Boulder, Colorado

SUMMARY

This report derives prediction curves of radio transmission loss and its long-term variability in time. The prediction parameters are angular distance and transmitting or receiving antenna height, with one antenna height fixed at 30 feet. The curves are based on observations of transmission loss over propagation paths in the area of the United States east of the Rocky Mountains, with data from the Pacific Coast shown for comparison.

INTRODUCTION

The prediction curves derived in this report depend upon a long-term program of measurements which was undertaken by the Central Radio Propagation Laboratory of the National Bureau of Standards, with the assistance of the Department of Defense, the Federal Communications Commission, several universities, and other agencies. Transmission loss was recorded over particular paths for at least a year to determine seasonal variations, whenever possible, and a number of paths were studied for much longer periods of time to determine year to year variability. The basic data for the analysis reported here are hourly median values of transmission loss at frequencies between 92 and 108 megacycles.

This paper first defines transmission loss and angular distance and then describes the data and methods of analysis used.

Transmission loss is defined as the ratio of total radiated power to the resulting signal power available from the loss-free receiving antenna. The advantages of this concept are explained in a recent paper by Norton[1/].

"Basic" transmission loss is defined as the transmission loss expected between isotropic antennas. If the basic transmission loss L_b is expressed in decibels and the frequency f_{mc} in megacycles, then a simple relationship exists between these quantities and the field strength E expressed in decibels above one microvolt per meter for one kilowatt of effective radiated power:

$$E = 139.37 + 20 \log_{10} f_{mc} - L_b$$

Values of basic transmission loss are presented in this paper as a function of the physical quantity "angular distance," which is the angle between the ray from the transmitting antenna to its radio horizon and a ray from the receiving antenna to its radio horizon, determined in the great circle plane containing both antennas. Angular distance was determined assuming an effective earth's radius equal to four-thirds the actual radius of the earth in order to allow for the effects of refraction in a radio standard atmosphere.

Over a smooth spherical earth the angular distance, θ, is equal to the distance between the transmitting and receiving antenna horizons divided by the effective radius of the earth. For receiving locations at radio line-of-sight, θ, is equal to zero, and beyond radio line-of-sight, θ is positive.

The difficult problem of defining antenna height over irregular terrain becomes less important when angular distance is used as a parameter instead of the propagation path distance d. When θ is constant, any increase in antenna height involves an increase in distance and in distance attenuation. The height gain and distance attenuation work in opposite directions, so that the net height gain for a constant θ is only a fraction of the corresponding height gain at a constant distance. If there is more distance attenuation than height gain, the net height gain for a constant θ is negative.

Reference to two recent papers prepared at the National Bureau of Standards [2, 3] will be required in order to understand the methods of analysis described in this paper. Reference 2 shows how angular distance enters into tropospheric propagation theory, and reference 3 describes an interpretation of the Booker-Gordon scattering theory upon which the analysis in this report depends. In this theory, angular distance is the basic parameter.

The curves presented here are designed to reflect "average" smooth earth conditions, not greatly affected by obstacle gain due to knife-edge diffraction. Where a hill acting as the radio horizon of an antenna is very high with respect to average terrain extending back to the antenna, it is expected that smooth earth theory will not correspond very closely to the physics of the propagation problem. A criterion for rejecting data corresponding to such very rough terrain profiles and involving "obstacle gain" is explained in Appendix II. It also explains how effective antenna heights are defined. Out of forty-two paths for which terrain profiles were available, only four were rejected from the analysis, so it may be seen that the present curves should be applicable to most commonly occurring propagation paths.

The phenomenon of obstacle gain due to knife-edge diffraction is treated in recent reports, by Dickson, Egli, Herbstreit, and Wickizer 4/, by Kirby and McQuate 5/, and by Dougherty 6/.

2. DESCRIPTION OF DATA

A recent report on radio transmission loss versus distance and antenna height at 100 megacycles 7/ describes the data in detail. It has been found that field strengths recorded at certain times of the day and in certain seasons of the year are systematically stronger than at other times. In order to allow to some extent for these systematic effects, the year was divided into two parts and the day into four parts, making eight "Time Blocks." Table I defines the time blocks used. The hours of the day were divided in the fashion shown mainly because the low point of the diurnal cycle in this type of data usually occurs between 1 PM and 6 PM. The year was divided in half to distinguish between high summer field strengths and low winter fields. Very few hourly medians were available in time blocks 7 and 8.

TABLE I

TIME BLOCKS

1	Nov - Apr	6 AM - 1 PM
2	Nov - Apr	1 PM - 6 PM
3	Nov - Apr	6 PM - 12 Mn
4	May - Oct	6 AM - 1 PM
5	May - Oct	1 PM - 6 PM
6	May - Oct	6 PM - 12 Mn
7	May - Oct	12 Mn - 6 AM
8	Nov - Apr	12 Mn - 6 AM

Once a division was made into time blocks, the basic data for analysis were values chosen from the cumulative distributions of hourly medians recorded during each of these time blocks over each path. Fig. 1 shows an example of such a cumulative distribution for station KXYZ-FM Houston, Texas, as recorded by the University of Texas at Austin.

From the data for each time of block, year, and propagation path, the transmission loss values exceeded 90%, 50%, and 10% of the hours were determined. These values correspond to field strengths exceeded 10%, 50%, and 90% of the hours, respectively. The time block medians were used to estimate the dependence of transmission loss on angular distance and antenna height, and the other data were needed in order to study long-term variability.

Appendix I gives pertinent information about the data used in the analysis.

3. METHODS OF ANALYSIS

A mathematical basis for tropospheric radio scattering has been formulated by Booker and Gordon[8,9] and by Staras[10]. The development of this theory for the purposes of the present analysis assumes a four-thirds earth standard atmosphere and simple isotropic scattering. The theory is important to the analysis of these data because they all represent conditions beyond the radio horizon, where tropospheric scattering is important.

Within the framework of the theory described in reference 3, only very simple assumptions with regard to meteorological factors are justified. It is assumed that at any two points in space separated by a distance r, the covariance with respect to time of the refractive index variations which give rise to scattering is of the following form:

$$C(r) = C(O) \exp(-r/\ell) , \qquad (2)$$

where C(O) is the time variance of the refractive index of the atmosphere and ℓ is the scale of turbulence of the atmosphere. The separation r may be in any direction, so the scattering is isotropic.

An estimate of the scale of turbulence was derived from data obtained in Texas and in Ohio by von Rosenberg, Crain, and Straiton of the University of Texas[11] and on Long Island by Birnbaum, Bussey, and Larson of the National Bureau of Standards[12]. Shown plotted in Fig. 2 are values for the scale of turbulence used to define the empirical relation:

$$\ell = \frac{70h}{h + 0.5} \qquad (3)$$

where ℓ is in meters and h is height above ground in thousands of feet.

Records of the variation of refractive index in time and space do not always indicate that the correlation function $C(r)$ is of the assumed form given by equation (2), so in determining the scale of turbulence, it was defined to be that value of ℓ which would make $C(r)/C(0) = \exp(-r/\ell)$ equal 0.5 at the value of r where the actual normalized autocorrelation was 0.5 in a record of refractive index fluctuations in space.

Scattering theory indicates that the power scattered from any volume element of the atmosphere is directly proportional to the value of $C(0)/\ell$ within the volume element. Radio transmission loss data were used to determine a functional dependence of the mean value of this parameter on the height above ground of the theoretical "center of scattering." All the data used to determine the variation of $C(0)/\ell$ with height correspond to angular distances greater than 20 milliradians (100 miles between radio horizons of the antennas). At these distances scattering is thought to be the propagation mechanism usually dominant at 100 megacycles.

Equation 24 in reference 3 shows how the parameter $C(0)/\ell$ enters into the scattering theory. Equations 15 and 25 in reference 3 define the location of the "scattering center." Equation 15 represents the weakest link in this approach to the theoretical analysis of transmission loss data, for the scattering centers given by this equation appear to be too high. A substantial improvement of the estimates given by Equation 15, however, will require a very elaborate theoretical analysis, which up to the present time has not been completed. The prediction curves shown here are largely determined by the experimental data and are little affected, even in their extrapolated portions, by the precise form of the theory.

To determine a functional dependence of the parameter $C(0)/\ell$ on height above ground, the methods of reference 3 were used. Each time block median (the median of all hourly medians in a time block) was corrected to correspond to transmission loss between isotropic antennas 500 feet high and 30 feet high by using the scattering theory.

The corrected data were used to obtain a curve for a 500 foot, 30 foot combination of antenna heights, and then scattering theory was used to extrapolate to other antenna height combinations. At short distances where scattering does not predominate, predictions are based on the Bremmer-Van der Pol diffraction theory for a smooth spherical earth. Reference 2 describes the method used for combining the diffracted and the scattered power at intermediate distances.

Both scattering theory and diffraction theory indicate that the ground wave is propagated beyond the horizon as though guided by the surface of the earth in such a fashion that energy spreads uniformly normal to the great circle plane between the antennas, but is confined in the vertical plane by the presence of a wave guide, the lower boundary of which is the earth's surface. Thus the spatial decay of the energy with distance is as $1/d$ rather than as $1/d^2$, which would be the case in free space. It follows that energy loss, or the basic transmission loss L_b expressed in decibels, will include a term equal to $-10 \log_{10} d$, resolving the transmission loss into terms dependent separately upon the physical distance d and the angular distance θ. In the present analysis, therefore, scattering theory was used to predict median basic transmission loss L_{bm} minus $10 \log_{10} d$, rather than to fit curves through observed values of L_{bm}. The origin and development of this feature of the analysis will be found in reference 2.

4. PREDICTION CURVES

Fig. 3 shows prediction curves of $L_{bm} - 10 \log_{10} d$ as a function of θ, with one antenna ranging from ten to five thousand feet and with the other antenna fixed at thirty feet. The circles in this figure are maximum and minimum values of the time block medians obtained for each of the paths used in the analysis. The X's in the figure represent maximum and minimum time block medians for three sets of Pacific Coast data rejected from the analysis. (They were rejected by the criterion for obstacle gain due to knife-edge diffraction which is explained in Appendix II). These extreme values of time block medians were obtained from samples which extend over several years in some cases and over a fraction of a year in other cases. In Appendix I, one-half the difference between these extremes is compared with the standard deviation of all the time block medians available for each path. Also listed in Appendix I are the periods of recording analyzed and the number of hours of data available in each time block for each propagation path.

Fig. 4 shows height-gain curves with θ a parameter; they extend over a height range for one antenna from 10 feet to 100,000 feet, with the height of the other antenna fixed at 30 feet. The curves have been made to pass through a reference point corresponding to a 500 foot, 30 foot combination of antenna heights.

To simplify the explanation of this curve, let $Z(h) = (L_{bm} - 10 \log_{10} d)_h$, where the values of $(L_{bm} - 10 \log_{10} d)$ are estimates for the antenna height indicated by the subscript h, with the other antenna height fixed at thirty feet. Plotted in Fig. 4 versus the antenna height h_1 in feet is the quantity

$$H_c(h_1, \theta) = Z(h_1) - Z(500), \tag{4}$$

An estimate of $Z(h_1)$ is obtained by adding H_c to the value of $Z(500)$ read from the 500 foot curve of Fig. 3. These height-gain curves in Fig. 4 are designed for use where θ is fixed and d is allowed to vary with h_1.

Particularly to be noted in Fig. 3 and in Fig. 4 is the small amount of height gain predicted by the scattering theory at a constant value of the angular distance θ. Most of the data, other than that obtained at the Cheyenne Mountain Field Station of the National Bureau of Standards correspond to transmitting antenna heights near 500 feet.

Fig. 5 shows median basic transmission loss L_{bm} versus antenna height for a series of constant distances from 50 to 600 miles. These curves assume a smooth four-thirds earth relationship between θ, d, and the antenna heights h_1 and h_2:

$$d = 5.28\ \theta + \sqrt{2h_1} + \sqrt{2h_2}, \tag{5}$$

where d is in miles, θ in milliradians, and h_1 and h_2 are in feet. Since all data are for $\theta > 0$, curves are not drawn in Fig. 5 within line of sight of the fixed antenna height h_2.

The basic prediction curves in Fig. 3 and in Fig. 4 were used to obtain estimates of transmission loss for each path and each time block for which data were available, and Fig. 6 shows the cumulative distribution of deviations of observed from predicted values of time block medians. The predictions included some correction for time of day and season. These corrections are discussed in some detail in Section 6 of this report.

An interesting point may be brought out about the comparison of data with the prediction curves of Fig. 3. The standard deviation of the departures from these basic prediction curves of all the time block medians analyzed is a little over 4 decibels. This corresponds closely with an estimate of variance due to terrain which was derived independently in a recent report by Bean[13].

On the average, time blocks 2 and 5 show basic transmission loss about two decibels greater, and time block 7 shows basic transmission loss about three decibels less than that observed during the other time blocks.

Though the median deviation of these data from the prediction curves is zero, it may be noted from Fig. 6 that extremely low fields are more common than equally high values. The predictions shown in Figs. 3 through 5 represent an "average" of all the data. Some time blocks were not recorded for as many hours as some other time blocks, and this "average" does not quite represent the expected median transmission loss for all-day, all-year conditions. A discussion of this aspect of the problem of prediction is presented in Section 6.

5. VARIABILITY IN TIME AS A FUNCTION OF θ

For each time block and each propagation path, a cumulative distribution was obtained of the hourly medians recorded, as illustrated in Fig. 1. From the data for each time block, year, and station, the transmission loss exceeded 90%, 50%, and 10% of the hours was determined. The convention is adopted that $E(T)$ represents the field strength exceeded $T\%$ of the hours and is expressed in decibels above one microvolt per meter for one kilowatt of effective radiated power, and that $L_b(T)$ corresponds with $E(T)$ and therefore represents the basic transmission loss exceeded $(100 - T)\%$ of the hours.

Let y_1 equal the difference between 10% and 50% fields, and let y_2 equal the difference between the 50% and 90% fields:

$$y_1 = L_b(50) - L_b(10) = E(10) - E(50) \qquad (6)$$

$$y_2 = L_b(90) - L_b(50) = E(50) - E(90) \qquad (7)$$

Both y_1 and y_2 are always positive numbers.

The observed differences y_{1o} and y_{2o} as determined for each time block, year, and station, were weighted. A weighted average was computed for each propagation path, using for each average all of the time blocks with data for that path. (This biases the results in favor of the time blocks in which there were the most data).

There were 38 of these weighted average values of y_{1o} and y_{2o}, and these values are plotted in Fig. 7. This figure shows the estimates of long-term variability of transmission loss versus angular distance for an "average" time block, as obtained by weighted least squares curve-fits of the data by certain functional forms.

In order to determine how to fit these functional forms to the data, a running average of the points taking five values of θ at a time was plotted. A straight line was fitted to the y_{1o} data and another to the y_{2o} data from line-of-sight to where θ = 12.2 milliradians. A function of the form $y = A + B(\theta - K \log_{10}\theta)$ was fitted to each set of data for θ greater than 17 milliradians. The data at angular distances greater than θ = 80 milliradians (obtained at one receiving location) seem to indicate an increase of variance beyond this angular distance. Such an increase seems unlikely, as scattering is occurring well up in the stratosphere, so a restriction was placed upon the curve fit $y = A + B(\theta - K \log_{10}\theta)$ to force the variance to decrease with increasing θ out to 150 milliradians. K was fixed at a value of $345.39 = 150 \text{ Log}_e 10$ in order to force the curves to have a slope of zero at 150 milliradians. Each curve was assumed to have a constant value independent of θ beyond 150 milliradians, where no data were available. On a smooth four-thirds earth, θ = 150 milliradians corresponds to a distance of 792 miles between the radio horizons of any two antennas. The curves in Fig. 7 may be used with confidence probably out to about 80 milliradians.

The two curve fits up to 12.2 and beyond 17 milliradians were blended together by taking a "firm grip on the pencil," starting from 8 milliradians and extending to 25 milliradians to give a smooth transition and to eliminate the end effects of the curve fits. The "firm grip on the pencil" was guided to a considerable extent by the weighted running average curves of the data in this range. The final curves of $y_1(\theta)$ versus θ and $-y_2(\theta)$ versus θ were then plotted on a linear θ scale, and are presented as Fig. 7.

6. DEVIATION OF PREDICTIONS FROM ALL-DAY, ALL-YEAR CONDITIONS

Next, an evaluation was made of the departures ΔL_o of observed median basic transmission loss $L_{bo}(50)$ for a given time block, year, and station from the predicted values $L_{bm} = L_b(50)$ of Fig. 3. These predicted values correspond to the "average" of the available data; this average is biased relative to all-day, all-year conditions by the fact that little data were available for the period from midnight to 6 AM.

It was noted that the deviations $\Delta L_o = L_{bo} - L_b$ tended to be greatest at angular distances where the long-term variance is large, and as a first approximation it was assumed that ΔL should depend upon θ in the same manner as the function $y_1(\theta)$ defined by the upper curve in Fig. 7. For each time block, a weighted mean value A_q of the quantities $\Delta L_o/y_1(\theta)$ was chosen to represent the average amount by which transmission loss in the qth time block departs from the prediction curves of Fig. 3. The deviation of the estimate of $L_{bq}(50)$ for the qth time block from the $L_b(50)$ of Fig. 3 is then $A_q y_1(\theta)$, and

$$L_{bq}(50) = L_b(50) + A_q y_1(\theta) = L_b(50) + \Delta L. \tag{8}$$

In Fig. 8 the quantity $\Delta L = A_q y_1(\theta)$ is plotted as a function of θ for each of the eight time blocks.

Table II gives the values of A_q for the eight time blocks. Note that, as would be expected, the resulting predicted values of transmission loss are larger for the winter time blocks than for the summer time blocks and the transmission loss is greatest in the afternoon and least in the midnight to 6 AM time blocks.

Also shown in Fig. 8, as a dashed curve, is the deviation of all-day, all-year predictions of L(50) from the estimates obtainable from Fig. 3; the method of obtaining this curve is explained below. The dotted curve in Fig. 8 shows the deviation from the estimates of Fig. 3 corresponding (a) to all year, and (b) to the period from 6 AM to midnight.

TABLE II

q = Time Block Number	A_q	B_{1q}	B_{2q}
1	-.0061	1.0969	1.0817
2	+.1953	.9137	.8816
3	-.1051	1.0110	1.0965
4	-.4348	1.1867	1.0907
5	+.1521	.7689	.6993
6	-.2902	1.0437	.9425
7	-.5999	1.1223	1.1737
8	-.1519	1.1711	1.1721

The observed differences y_{1o} and y_{2o} for each time block, year, and station were fitted to functions of the form $B_1 y_1(\theta)$ and $B_2 y_2(\theta)$, where the smooth curves in Fig. 7 define $y_1(\theta)$ and $y_2(\theta)$. Values of B_1 and B_2 for each time block were weighted averages of quantities $y_{1o}/y_1(\theta)$ and $y_{2o}/y_2(\theta)$ and are listed in Table II. In order to obtain a cumulative distribution for each time block at each of several values of θ between 0 and 110 milliradians, the following method was used:

Long-term cumulative distributions are almost log-normal, so for the qth time block the quantity $B_1 y_1(\theta)$ was used to define the slope of a log-normal distribution assumed to hold for field strengths exceeding the median, and $B_2 y_2(\theta)$ defined the slope of another log-normal distribution, assumed to hold for field strengths less than the median. For instance, for time block q:

$$\begin{aligned} L_{bq}(1) &= L_{bq}(50) - 1.815 B_{1q} y_1(\theta) \\ &= L_b(50) + A_q y_1(\theta) - 1.815 B_{1q} y_1(\theta) \qquad (9) \end{aligned}$$

Next, at each value of θ, a combined distribution was obtained by averaging the eight percentages at each of several convenient levels of transmission loss; these combined distributions are believed to be representative of what would have been obtained from data available all day and all year from every propagation path. The averaging of percentages was weighted in accordance with the possible number of observations in each time block, not in accordance with the actual number of hours of observation. All-day, all-year predictions of L(50) derived from the dashed curves of Fig. 8 correspond to the median values of these combined distributions. The dotted curve in Fig. 8 was obtained in a similar fashion, averaging cumulative distributions for time blocks 1 through 6.

Fig. 9 presents the results of combining all of the time blocks as a graph of y(T) versus θ, where

$$y(T) = L(50) - L(T) = E(T) - E(50) \tag{10}$$

Fig. 10 presents the corresponding graph for the period 6 AM to midnight.

7. USE OF THE CURVES

Most of the data upon which the prediction analyses are based correspond to antenna heights near the 500 foot, 30 foot combination. It is expected that the use of angular distance as a parameter will make it possible to safely extrapolate to other antenna height combinations. Estimates of the time variance described as a function of angular distance alone are expected to be valid over a wide range of antenna height from beyond line-of-sight all the way back to where $\theta = 0$.

In order to predict the basic transmission loss $L_{bp}(T)$ corresponding to field strengths exceeded T% of the time at an average location over an average 24-hour, 12-month period, either Fig. 3 or Fig. 5 is used to find $L_b(50)$, and this is combined with estimates of ΔL from the dashed curve of Fig. 8 and estimates of y(T) in Fig. 9 in accordance with the formula:

$$L_{bp}(T) = L_b(50) + \Delta L - y(T) \tag{11}$$

Estimates for the period 6 AM to midnight use the dotted curve of Fig. 8 and the y(T) from Fig. 10.

8. COMPARISON WITH OTHER PREDICTIONS

The prediction curves in this report introduce the application of the concept of angular distance to the analysis of data from all over the country, and use of the scattering theory makes possible an extrapolation of results to much higher antennas than are represented in the data. Fig. 11 compares 500 foot, 30 foot, 100 megacycle 1% and 50% estimates of basic transmission loss as obtained by the FCC Ad Hoc Committee in 1949[14,15] and as derived by CRPL in 1953[7] with the present 500 foot, 30 foot, 100 megacycle estimates. It will be noted that the 1% estimates all agree closely out to 400 miles. Where the present median estimates show more distance attenuation than the 1953 estimates at the larger distances, part of the explanation lies in the fact that the manner of fitting an exponential function to $C(0)/\ell$ in the region beyond $\theta = 50$ milliradians forces the curve to go about ten decibels above data available at around 60 milliradians and ten decibels below data available at around 100 milliradians (600 miles), while the 1953 curves were made to go through data available at 600 miles. The FCC Ad Hoc curves depended upon 1% fields at the larger distances, and the Ad Hoc 50% curves corresponded to an estimate of the difference between the 1% and the 50% fields which was larger at great distances than the present estimates.

It should be noted at this point that Figs. 9 and 10 show estimates of the variability of hourly medians, not the variability of instantaneous values. The variance of transmission loss values recorded at every instant over a long period would also include within-the-hour variability. Where tropospheric scattering is fairly "pure," and Rayleigh distributions of signal voltage are expected within short periods of time of the order of ten minutes to a few hours, the variance of instantaneous values may be more than twice as much as the variance of hourly medians. Reference 16 gives a theoretical treatment of this subject by McCrossen[16]. A description of within-the-hour cumulative distributions as observed at 100 and 1000 megacycles in the CRPL Cheyenne Mountain Experiment will be found in a recent paper by Janes[17]. Theoretical reasons for expecting Rayleigh-distributed fields in tropospheric scattering are developed in a recent paper by Staras[18] and a paper by Norton, Short, and Mansfield[19] gives the appropriate distributions in the region where both diffraction and scattering are important.

1/ K.A. Norton, "Transmission Loss in Radio Propagation", Proc. IRE, Vol. 41, January, 1953.

2/ K.A. Norton, "The Role of Angular Distance in Tropospheric Radio Wave Propagation", in preparation.

3/ J.W. Herbstreit, K.A. Norton, P.L. Rice and G.E. Schafer, "Radio Wave Scattering in Tropospheric Propagation", 1953 Convention Record of the IRE, Part 2, Antennas and Communications pp. 85-93.

4/ F.H. Dickson, J.J. Egli, J.W. Herbstreit, and G.S. Wickizer, "Large Reductions of VHF Transmission Loss and Fading by the Presence of a Mountain Obstacle in Beyond-Line-of-Sight Paths", Proc. IRE, Vol. 41, No. 8, August, 1953, p. 967.

5/ R.S. Kirby and P.L. McQuate, "Obstacle Gain at 60 Mc Over Pikes Peak", in preparation.

6/ H.T. Dougherty, "A New Technique for the Evaluation of the Effects of Terrain upon Propagation at VHF and UHF", in preparation.

7/ P.L. Rice and F.T. Daniel, "Radio Transmission Loss Versus Distance and Antenna Height at 100 Megacycles", in preparation.

8/ H.G. Booker and W.E. Gordon, "A Theory of Radio Scattering in the Troposphere", Proc. IRE, Vol. 38, pp. 401-412, April, 1950.

9/ W.E. Gordon, "The Scattering of Radio Waves by Turbulence in the Troposphere", Research Report EE 163, Cornell University, Investigation of Air-to-Air and Air-to-Ground Electromagnetic Propagation Final Report Part VI, September 15, 1953.

10/ Harold Staras, "Scattering of Electromagnetic Energy in a Randomly Inhomogeneous Atmosphere", Jour. Appl. Phys. Vol. 23, pp. 1152-1156, October, 1952.

11/ C.E. von Rosenberg, C.M. Crain and A.W. Straiton, "Atmospheric Refractive-Index Fluctuations as Recorded by an Airborne Microwave Refractometer", Univ. of Texas EERL Report No. 6-01, February 6, 1953.

12/ George Birnbaum, H.E. Bussey, and R.R. Larson, "The Microwave Measurement of Variations in Atmospheric Refractive Index", private communication, 1952.

13/ Bradford R. Bean, "Estimation of the Annual, Geographic, and Terrain Variances of 100 Mc Transmission Loss", presented at the National Bureau of Standards Boulder Laboratories Dedication Program, September 8-14, 1954.

14/ Report of the Ad Hoc Committee for the Evaluation of the Radio Propagation Factors Concerning FM and TV, FCC Mimeos Nos. 36728, May 26, 1949; 36830, May 31, 1949; and 54832, July 7, 1950.

15/ E.E. Allen, W.C. Boese, and H. Fine, "Summary of Tropospheric Propagation Measurements and the Development of Empirical VHF Propagation Charts (Revised), Reference D to the Report of the Ad Hoc Committee for the Evaluation of the Radio Propagation Factors Concerning FM and TV, FCC Mimeo No. 36728, May 26, 1949.

16/ Garner McCrossen, "Long-Term Theoretical Cumulative Distribution Function for Tropospherically Scattered Fields", in preparation.

17/ H.B. Janes, "An Analysis of Within-the-Hour Fading in 100-1000 Mc Transmissions", in preparation.

18/ Harold Staras, "The Statistical Properties of a Tropospherically Scattered Radio Signal", presented at the joint meeting of URSI-IRE, May 3-6, Washington, D.C.; manuscript in preparation.

19/ K.A. Norton, P.J. Short and William Mansfield, "The Cumulative Probability Distribution of the Instantaneous Resultant Amplitude of the Vector Sum of a Constant Component and a Randomly Phased Rayleigh Distributed Varying Component", in preparation.

APPENDIX I

Path No.	Transmitter	Receiver
1*	KFOR, Lincoln, Nebr.	FCC, Grand Island, Nebr.
2*	WCAC, Anderson, S.C.	FCC, Powder Springs, Ga.
3*	WEEU, Reading, Pa.	FCC, Laurel, Md.
4*	WIP, Philadelphia, Pa.	FCC, Laurel, Md.
5*#	WMRC, Greenville, S.C.	FCC, Powder Springs, Ga.
6*	WTIC, Hartford, Conn.	FCC, Millis, Mass.
7*#	WEST, Easton, Pa.	Pa. State College, State College, Pa.
8*	WMBI, Chicago, Ill.	Univ. of Ill., Urbana, Ill.
9*#	WCOL, Columbus, Ohio	United Broadcasting Co., Hudson, Ohio
10*	WHKC, Columbus, Ohio	United Broadcasting Co., Hudson, Ohio
11*	WKBN, Youngstown, Ohio	United Broadcasting Co., Hudson, Ohio
12*#	WVKO, Columbus, Ohio	United Broadcasting Co., Hudson, Ohio
13*	WDKA, Pittsburgh, Pa.	United Broadcasting Co., Hudson, Ohio
14*#	KIXL, Dallas, Texas	University of Texas, Austin, Texas
15*#	KLTI, Longview, Texas	University of Texas, Austin, Texas
16*#	KPRC, Houston, Texas	University of Texas, Austin, Texas
17 #	KRBC, Abilene, Texas	University of Texas, Austin, Texas
18*#	KWKH, Shreveport, La.	University of Texas, Austin, Texas
19*#	KXYZ, Houston, Texas	University of Texas, Austin, Texas
20*#	WFAA, Dallas, Texas	University of Texas, Austin, Texas
21*	CRPL, Cheyenne Mt. Colorado Springs, Colo.	CRPL, Kendrick, Colorado
22*	CRPL, Cheyenne Mt. Colorado Springs, Colo.	CRPL, Karval, Colorado
23*	CRPL, Cheyenne Mt. Colorado Springs, Colo.	CRPL, Haswell, Colorado
24*#	CRPL, Cheyenne Mt. Colorado Springs, Colo.	CRPL, Garden City, Kansas
25*#	CRPL, Cheyenne Mt. Colorado Springs, Colo.	CRPL, Anthony, Kansas
26*	CRPL, Cheyenne Mt. Colorado Springs, Colo.	CRPL, Haswell, Colo.
27*#	CRPL, Cheyenne Mt. Colorado Springs, Colo.	CRPL, Garden City, Kansas

APPENDIX I (continued)

28*#	CRPL, Cheyenne Mt. Colorado Springs, Colo.	CRPL, Anthony, Kansas
29*#	CRPL, Cheyenne Mt. Colorado Springs, Colo.	CRPL, Fayetteville, Arkansas
30*	CRPL, Camp Carson, Colo.	CRPL, Kendrick, Colorado
31*	CRPL, Camp Carson, Colo.	CRPL, Karval, Colorado
32*	CRPL, Camp Carson, Colo.	CRPL, Haswell, Colorado
33*#	CRPL, Camp Carson, Colo.	CRPL, Garden City, Kansas
34*#	CRPL, Camp Carson, Colo.	CRPL, Anthony, Kansas
35*#	CRPL, Camp Carson, Colo.	CRPL, Fayetteville, Arkansas
36*#	CRPL, Pikes Peak, Colo.	CRPL, Garden City, Kansas
37*#	CRPL, Pikes Peak, Colo.	CRPL, Anthony, Kansas
38*#	CRPL, Pikes Peak, Colo.	CRPL, Fayetteville, Arkansas

* Refers to data used in investigating variability in time as a function of θ

\# Refers to data used in deriving an expression for $C(0)/\ell$ as a function of θ

Path No.	Path Distance d (statue miles)	Angular Distance θ (milliradians)	Frequency (megacycles)	Height of Trans-mitting Antenna Above Ground (ft)	Effective Height of Transmitting Antenna (ft)	Height of Receiving Antenna Above Ground (ft)	Total Height-Gain Correction to 500' and 30' Antennas (decibels)
1	93.2	14.6	101.9	329	411	45	+1.8
2	127.5	19.8	101.1	418	412	30	0
3	95.4	16.4	92.9	80	534	30	0
4	104.1	12.2	93.3	510	555	30	0
5	151.5	23.4	94.9	162	1167	30	0
6	80.6	15.7	96.5	302	1200	30	0
7	139.3	36.7	107.9	172	247	63	+1.9
8	126.0	16.1	95.5	492	400	90	+4.0
9	121.2	20.1	92.3	425	402	30	0
10	125.0	19.4	98.7	620	718	31	0
11	44.9	3.6	98.9	490	592	30	+0.1
12	118.9	20.9	94.7	221	335	30	0
13	96.7	12.2	92.9	540	736	30	0
14	175.9	32.3	104.5	520	553	32	+0.2
15	227.2	40.4	105.9	320	305	32	+0.3
16	147.8	23.8	102.9	342	348	32	+0.3
17	175.6	39.1	96.9	400	231	32	+0.3
18	277.0	47.4	94.5	450	399	32	+0.2
19	147.8	20.3	96.5	438	442	32	+0.3
20	174.2	32.5	97.9	548	488	32	+0.2
21	49.4	1.0	92	30	1662	37	+0.7
22	70.2	4.1	92	30	1742	37	+1.3
23	96.8	6.5	92	30	1672	37	+1.6
24	226.6	31.3	92	30	1672	37	0
25	393.6	63.5	92	30	1728	39	-0.5
26	96.6	1.8	100	55	2271	19	-3.1
27	226.5	28.1	100	55	2271	19	-2.9
28	393.5	58.5	100	55	2002	39	-1.6
29	617.1	98.3	100	55	2002	38	-1.3
30	46.6	5.6	100	40	711	19	-2.6

Path No.	Path Distance d (statute miles)	Angular Distance θ (milliradians)	Frequency (megacycles)	Height of Transmitting Antenna Above Ground (ft)	Effective Height of Transmitting Antenna (ft)	Height of Receiving Antenna Above Ground (ft)	Total Height-Gain Correction to 500' and 30' Antennas (decibels)
31	68.0	8.5	100	40	725	19	-2.5
32	93.8	11.5	100	40	728	19	-2.5
33	223.6	38.4	100	40	730	19	-1.8
34	390.7	68.0	100	40	728	39	+0.2
35	614.0	107.8	100	40	730	38	-0.1
36	237.1	20.6	100	30	7800	19	-5.0
37	404.1	50.9	100	30	7800	39	-2.5
38	628.1	90.6	100	30	7800	38	-3.8

Path No.	Transmitting Antenna Gain, G_t, in decibels	Receiving Antenna Gain, G_r, in decibels	$G_t + G_r - G_p$ in decibels (see Appendix I to Ref. 7)	$[L_{bm} - 10 \log_{10} d]^{\#} = Z$ in decibels	Standard deviation σ_Z in decibels	One half the maximum range of observed time block median basic transmission loss L_{bm} (decibels)	$[L(50)-L(10)]^{*} = y_1$ in decibels.	$[L(90) - L(50)]^{*} = y_2$ in decibels
1 *	11.3	2.15	0	-----	3.4	5.2	9.6	8.2
2 *	8.8	2.15	0	-----	2.0	2.7	10.0	8.3
3 *	8.1	2.15	0	-----	1.3	1.8	6.9	3.5
4 *	9.9	2.15	0	-----	3.0	4.7	11.9	7.7
5#*	----	2.15	0	154.2	5.1	6.9	7.9	7.2
6 *	9.4	2.15	0	-----	2.3	3.9	7.2	3.7
7#*	8.2	2.15	0	161.3	1.9	2.6	6.5	5.0
8 *	9.9	2.15	0	-----	2.7	4.9	10.1	9.3
9#*	8.4	2.15	0	148.2	5.0	9.3	10.2	9.1
10 *	9.0	2.15	0	-----	2.8	4.1	9.8	8.6
11 *	7.6	2.15	0	-----	2.3	3.8	2.7	2.6
12#*	9.9	2.15	0	157.0	0.8	0.9	5.3	3.8
13 *	8.4	2.15	0	-----	1.3	1.6	7.8	4.5
14#*	8.8	2.15	0	159.3	4.3	7.1	8.1	6.3
15#*	7.7	2.15	0	167.1	2.1	3.2	5.0	3.7
16#*	9.9	2.15	0	154.8	3.1	5.6	8.5	7.2
17#	8.8	2.15	0	162.3	1.1	1.4	---	---
18#*	9.7	2.15	0.2	168.1	2.0	5.0	5.2	3.8
19#*	3.9	2.15	0	153.8	2.6	3.6	9.5	8.1
20#*	8.2	2.15	0	164.7	1.8	2.3	6.7	4.9
21 *	9	2.15	0	-----	0.4	0.5	2.1	1.6
22 *	9	2.15	0	-----	0.8	1.3	3.3	2.3
23 *	9	2.15	0	-----	2.8	4.6	7.6	6.8
24#*	9	2.15	0	177.0	1.4	2.2	5.3	5.3
25#*	9	12.3	0.6	187.1	1.1	1.4	2.5	2.5
26 *	10	2.15	0	-----	2.3	3.8	5.5	4.2
27#*	10	2.15	0	170.3	4.6	5.8	7.3	8.4
28#*	10	17	0.7	185.5	6.2	8.9	4.0	5.6
29#*	10	19	1.3	198.1	1.8	3.1	3.9	5.5
30 *	14	2.15	0	----	1.2	1.9	3.2	1.7

Path No.	Transmitting Antenna Gain, G_t, in decibels	Receiving Antenna Gain, G_r, in decibels	$G_t + G_r - G_p$ in decibels (see Appendix I to Ref. 7)	$[L_{bm} - 10 \log_{10} d]^{\#} = Z$ in decibels	Standard deviation σ_Z in decibels	One half the maximum range of observed time block median basic transmission loss L_{bm} (decibels)	$[L(50) - L(10)]^{*} = y_1$ in decibels	$[L(90) - L(50)]^{*} = y_2$ in decibels
31 *	14	2.15	0	-----	2.4	4.0	7.4	2.3
32 *	17	2.15	0	-----	4.6	7.1	6.8	5.1
33#*	19	2.15	0.4	175.3	5.6	6.4	6.5	2.7
34#*	18	17	1.2	187.4	4.6	6.6	2.7	2.6
35#*	18	19	1.8	202.5	1.6	2.4	4.1	6.8
36#*	9	2.15	0	158.4	1.1	1.4	3.1	5.3
37#*	9	16	0.7	172.0	2.7	3.4	8.5	4.2
38#*	9	19	1.2	191.0	1.3	1.7	8.6	3.5

Path No.	Period of Recording Analyzed	Number of Hours of Data Available in Each Time Block							
		#1	#2	#3	#4	#5	#6	#7	#8
1	2/19/51 - 3/31/52 3 PM - 12 Mn	0	723	1314	0	547	1074	0	0
2	5/1/51 - 11/30/51 3 PM - 11 PM	108	110	148	181	559	885	0	0
3	9/5/51 - 3/15/52 (no date 10/51 or 11/51) 1 PM - 8 PM	0	403	303	0	125	54	0	0
4	3/9/51 - 3/31/52 9 AM - 12 Mn	847	997	1093	852	897	874	0	0
5	2/23/51 - 11/30/51 3 PM - 9 PM	0	287	311	0	531	581	0	0
6	7/1/51 - 3/31/52 5 AM - 1 AM	972	711	867	847	609	737	212	272
7	7/31/51 - 4/30/52 6 AM - 1 AM	1121	835	1018	602	442	531	67	71
8	3/1/41 - 3/31/52 6 AM - 10 PM	1344	991	804	1189	897	728	311	363
9	4/14/50 - 4/30/52 6 AM - 1 AM	2324	1867	2251	2447	1794	2172	0	0
10	4/28/50 - 4/30/52 6 AM - 1 AM	2321	1567	2027	2414	1715	2093	429	1369
11	8/4/50 - 4/30/52 3 PM - 12 Mn	0	1060	2080	0	960	1347	0	0
12	4/1/51 - 4/27/51 12 N - 11 PM	40	133	133	0	0	0	0	0
13	2/25/52 - 4/30/52 10 AM - 12 Mn	197	320	392	0	0	0	0	0

14	6/13/50 - 4/30/52 (no data 8/50 or 9/50) 8 AM - 7 AM	2270	1705	2132	1658	1256	1550	1534	2108
15	6/13/51 - 4/30/52 8 AM - 11 PM	783	848	869	658	666	673	0	0
16	5/1/49 - 6/13/51 (no data 11/17/49 to 2/2/50	1658	1323	1097	2019	1822	1782	0	0
17	4/14/50 - 6/10/50 3 PM - 9 PM	0	51	50	0	115	116	0	0
18	8/1/51 - 4/30/52 5 AM - 1 AM	1246	875	1080	608	442	534	166	334
19	6/14/51 - 4/30/52 7 AM - 11 PM	995	818	855	792	669	653	0	0
20	11/1/49 - 8/31/50 7 PM - 10 PM	792	785	719	0	365	484	0	0
21	1952 and 1953 All Hours	727	724	799	0	0	0	0	781
22	1952 and 1953 All Hours	872	883	918	0	0	0	0	908
23	1952 and 1953 All Hours	638	618	695	0	0	0	0	686
24	1952 and 1953 All Hours	357	373	406	0	0	0	0	394
25	1953 All Hours	28	36	34	0	0	0	0	36
26	1952 and 1953 All Hours	1034	1039	1120	758	775	829	796	1093
27	1952 and 1953 All Hours	524	520	571	556	542	603	635	571
28	1952 and 1953 All Hours	109	104	112	45	39	45	49	115

29	1952 and 1953								
	All Hours	5	4	1	25	35	36	23	7
30	1952 and 1953								
	All Hours	21	21	21	12	13	16	12	23
31	1952 and 1953								
	All Hours	3	3	5	18	18	19	18	6
32	1952 and 1953								
	All Hours	24	21	21	22	23	21	21	23
33	1952 and 1953								
	All Hours	7	9	9	19	19	18	19	8
34	1952 and 1953								
	All Hours	18	15	14	16	20	18	16	20
35	1952 and 1953								
	All Hours	3	2	3	11	14	15	12	9
36	1952								
	All Hours	0	0	0	6	7	6	6	0
37	1952								
	All Hours	0	0	0	12	15	12	15	0
38	1952								
	All Hours	0	0	0	10	15	11	6	0

APPENDIX II

DEFINITION OF ANTENNA HEIGHT

The angular distance θ which was used as a parameter in this analysis contains the major effects of both path distance and antenna height. The height gain realized from the directivity of the lobe structure at each end of the path needs to be taken into account. This height gain is a second-order correction.

In order to calculate this correction, effective antenna height is defined as the height of the antenna above an equivalent smooth spherical four-thirds earth fitted by least squares to the central eight-tenths of the terrain along the great circle path which extends from the antenna to its four-thirds earth radio horizon. The initial one-tenth of the terrain is ignored because it is assumed that in the lower regions of the scattering volume, lobery is unaffected by the terrain near the antenna. The final one-tenth of the terrain is omitted because it is assumed that the critical lobery is unaffected by terrain irregularities in the immediate vicinity of the radio horizon.

This definition of effective antenna height was not satisfactory for most receiving antennas. Their height above ground was small with respect to the average terrain irregularities. In such cases, some effective heights were found to be an order of magnitude or more greater than the structural antenna heights. The structural height was used, therefore, for receiving antennas, and the more complicated definition of effective antenna height was used only for transmitting antennas, which were in general much higher than the receiving antennas.

Although much further work needs to be done to obtain an adequate definition for the "effective antenna height" over irregular terrain, it should be noted that the use of angular distance, θ, has made this less urgent, since these "effective antenna heights" enter into the calculations only in connection with second-order corrections.

CRITERION FOR REJECTING DATA

The curves in this report are designed to reflect "average" smooth earth conditions, not too seriously affected by obstacle gain effects. Where the hill which acts as a radio horizon is very high with respect to average terrain extending back to the antenna, it is to be expected that the smooth earth theory used in this analysis may not correspond very closely with the physics of the problem. Accordingly, a criterion was adopted for rejecting data where the geometry of a terrain profile indicated that smooth earth theory might not be adequate for analyzing transmission loss over the propagation path. A smooth spherical four-thirds earth curve was fitted to the central eight-tenths of the terrain from each antenna to its four-thirds earth radio horizon, and a second such curve was fitted under the restriction that it had to pass through the radio horizon. The angle between the radii of these two curves was added to the corresponding angle obtained from curve-fits at the other end of the path, and the sum of these two angles, $c_t + c_r$, was adopted as a criterion for the reliability of the smooth earth theory. Whenever $c_t + c_r$ exceeded ten milliradians, the data corresponding to that propagation path were rejected from the analysis on the assumption that obstacle gain effects might be large.

CUMULATIVE DISTRIBUTION OF HOURLY MEDIAN TRANSMISSION LOSS RECORDED AT AUSTIN, TEXAS FROM KXYZ-FM, HOUSTON, TEXAS BETWEEN JUNE 14, 1951 AND OCTOBER 31, 1951, 6 P.M.-11 P.M. C.S.T.

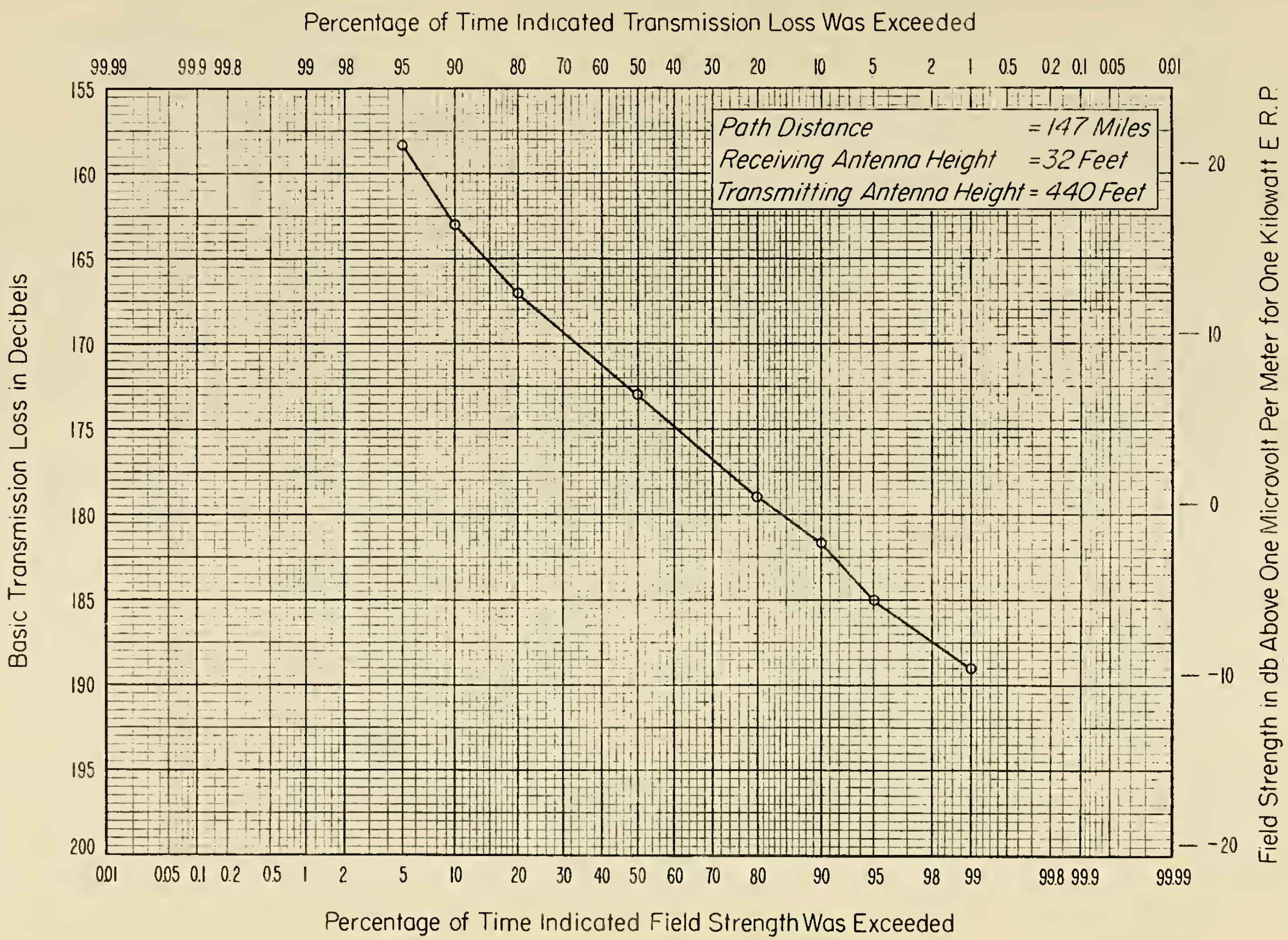


Figure 1

SCALE OF TURBULENCE VERSUS HEIGHT

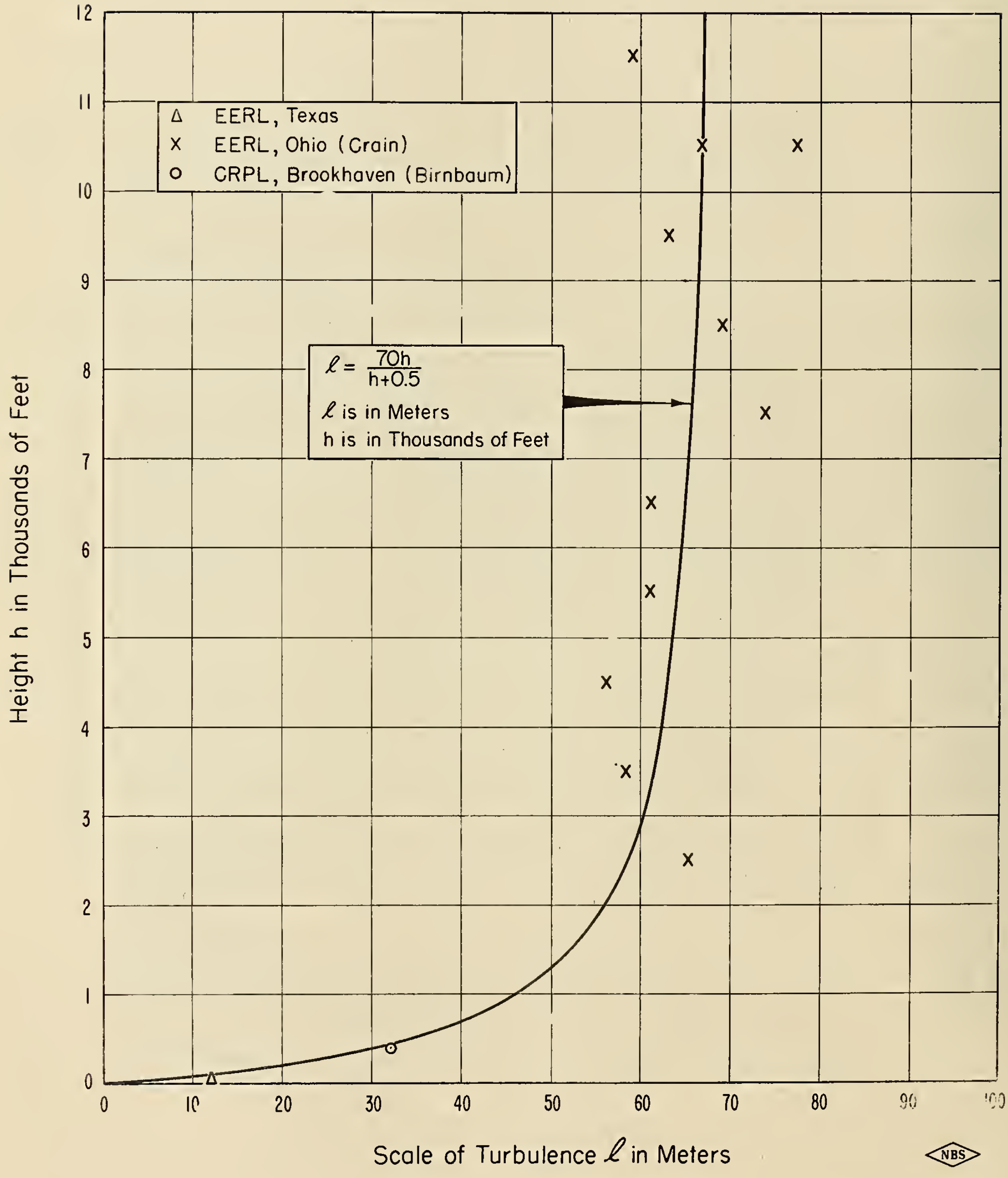


Figure 2

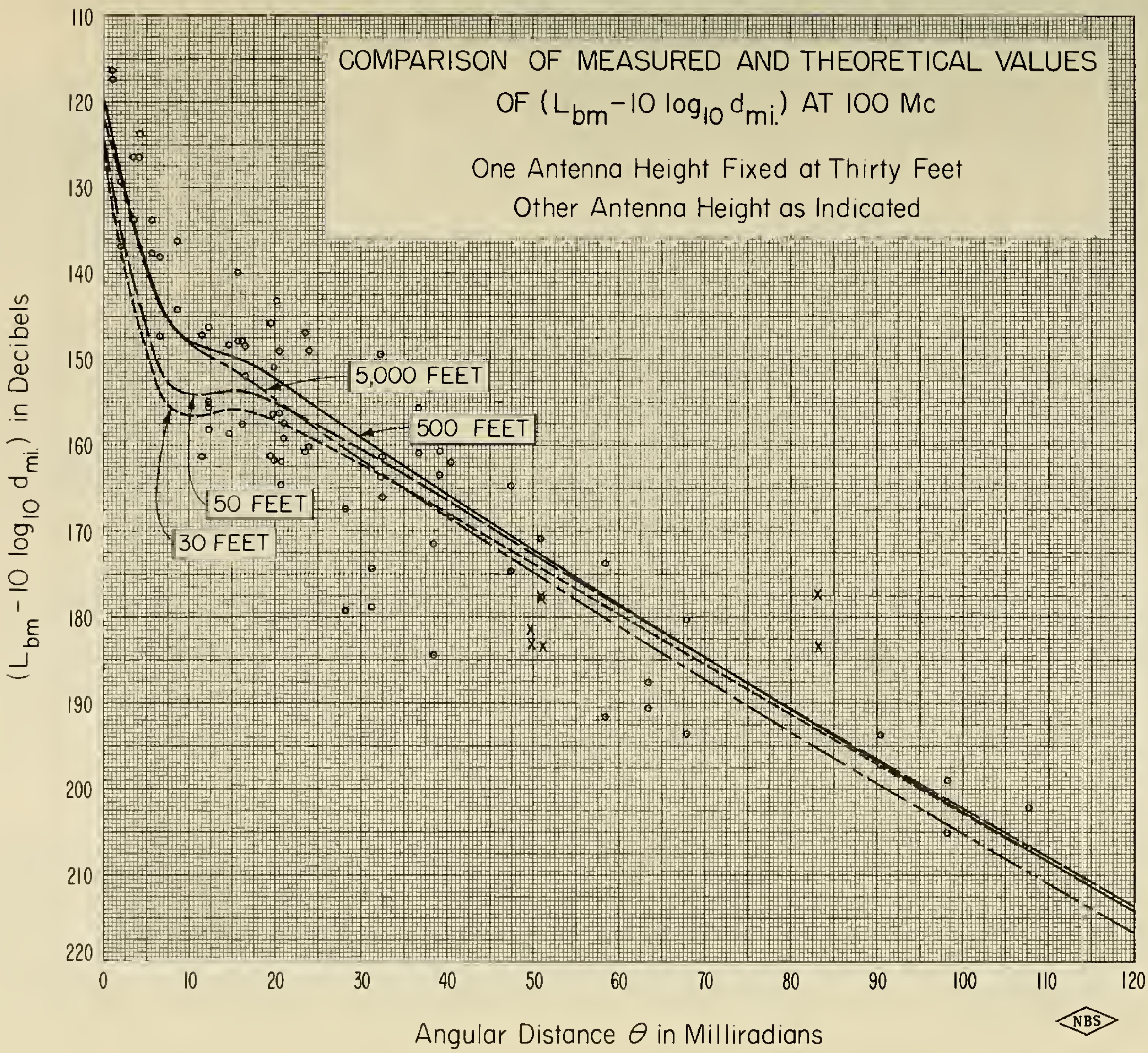

COMPARISON OF MEASURED AND THEORETICAL VALUES
OF (L_{bm} − 10 $\log_{10} d_{mi.}$) AT 100 Mc
One Antenna Height Fixed at Thirty Feet
Other Antenna Height as Indicated
5,000 FEET
500 FEET
50 FEET
30 FEET
(L_{bm} − 10 $\log_{10} d_{mi.}$) in Decibels
Angular Distance θ in Milliradians
110
120
130
140
150
160
170
180
190
200
210
220
0
10
20
30
40
50
60
70
80
90
100
110
120
NBS

Figure 3

ANTENNA HEIGHT GAIN $H_c(h_1, \theta)$ AT 63 MEGACYCLES

For Constant Angular Distance θ as Indicated

Antenna Height $h_2 = 30$ Feet

$$L(h_1, \theta) = L(500, \theta) + H_c(h_1, \theta) + 10 \log_{10} (d_{h_1} / d_{500})$$

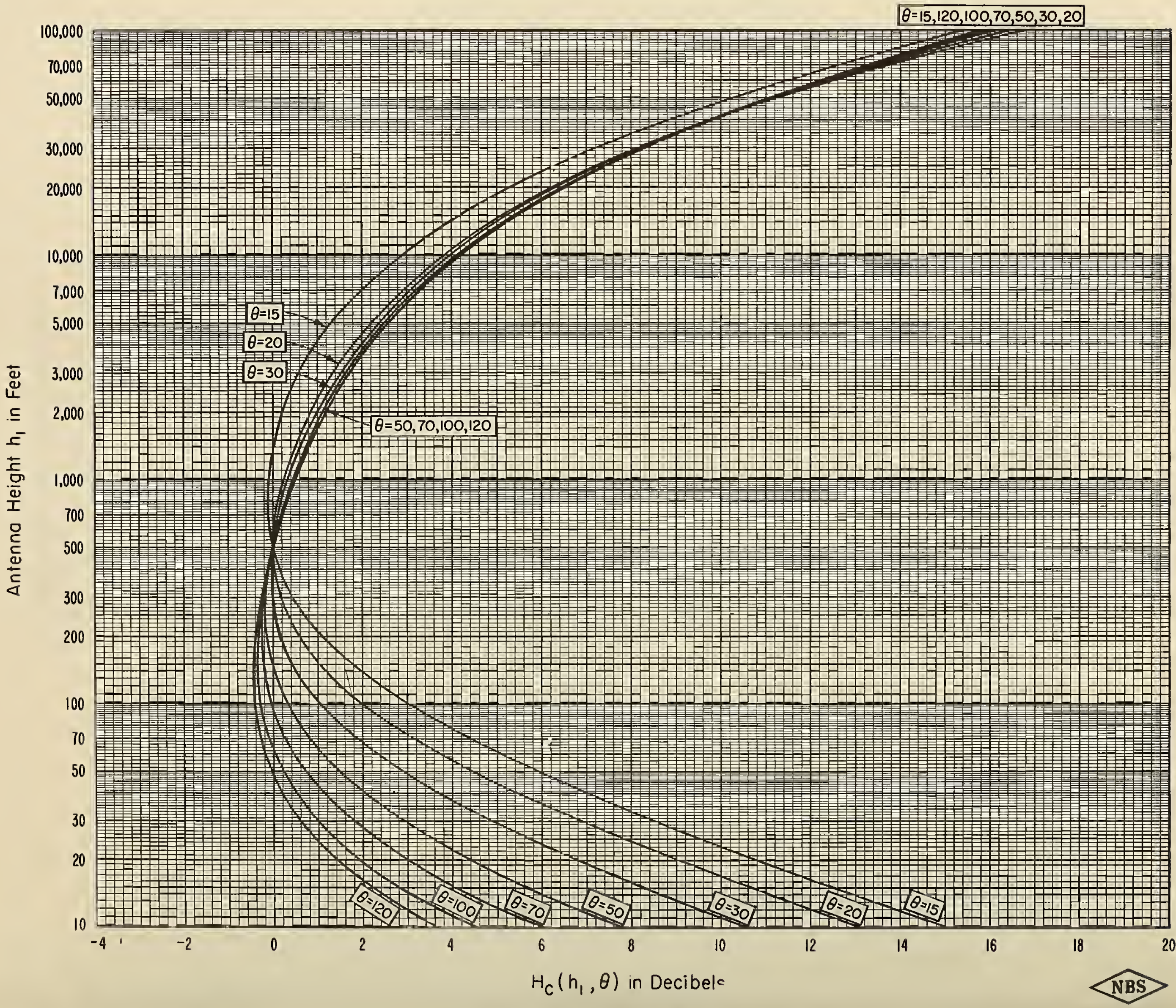
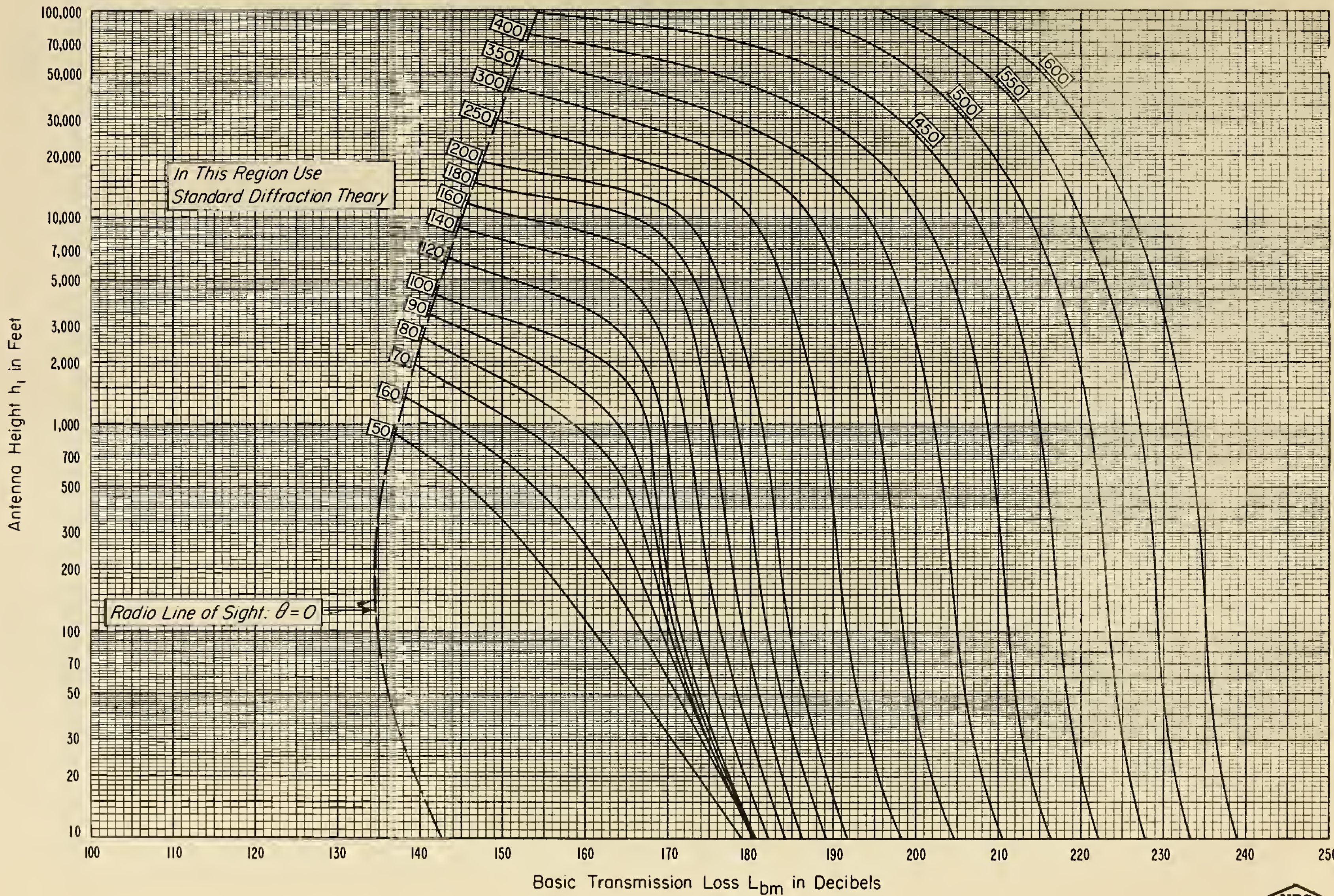


Figure 4

MEDIAN BASIC TRANSMISSION LOSS
VERSUS
ANTENNA HEIGHT h_1 AND DISTANCE d AT 100 MEGACYCLES
WITH ANTENNA HEIGHT h_2 = 30 FEET



NBS

Figure 5

CUMULATIVE DISTRIBUTION
OF DEVIATIONS OF 100 MC TIME BLOCK MEDIAN
TRANSMISSION LOSS DATA FROM PREDICTED VALUES

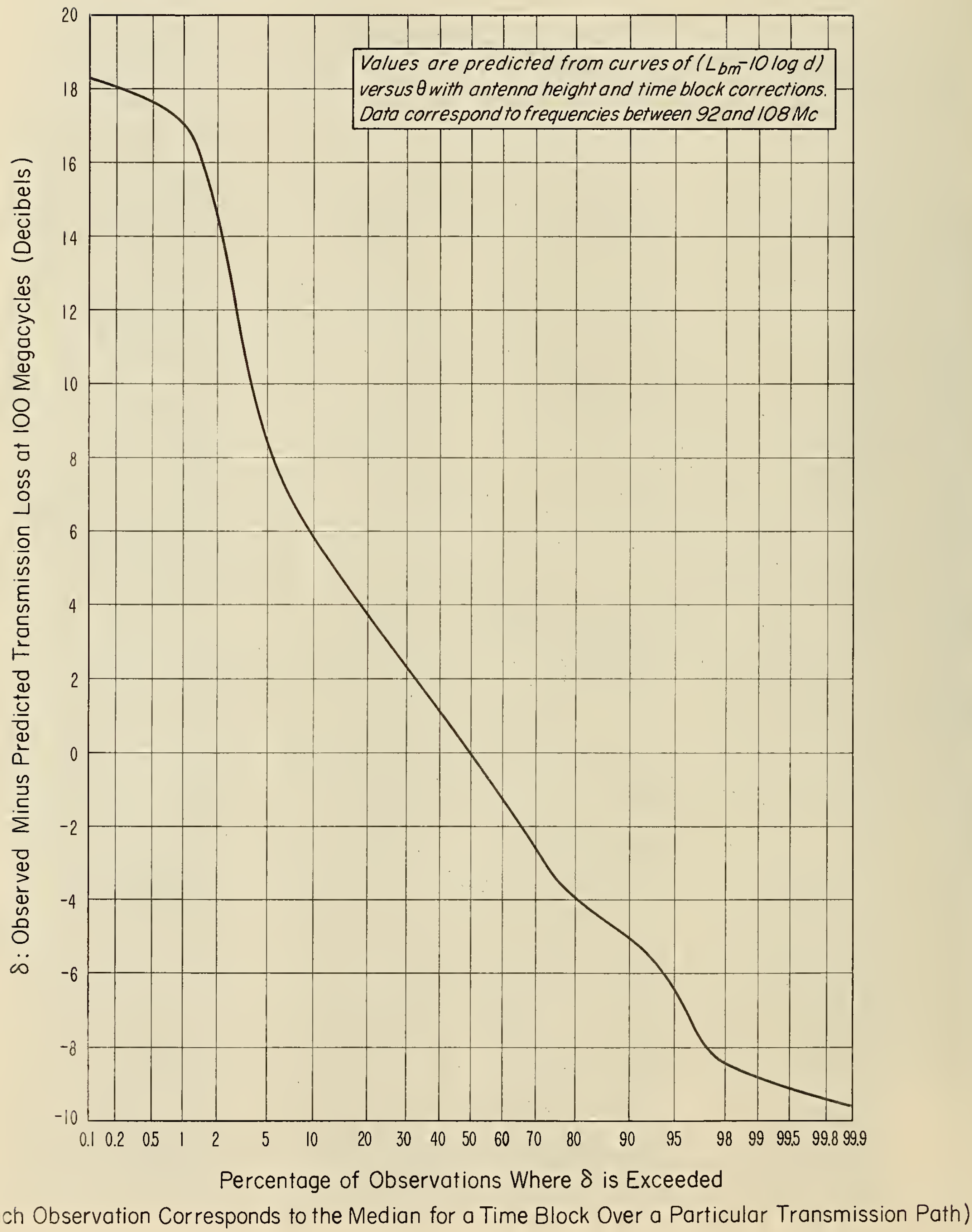


Figure 6

LONG-TERM VARIABILITY OF TRANSMISSION LOSS VERSUS ANGULAR DISTANCE
AS DETERMINED AT 100 MC

DIFFERENCES BETWEEN 10% AND 50% FIELDS AND 50% AND 90% FIELDS
AS A FUNCTION OF THE ANGULAR DISTANCE θ

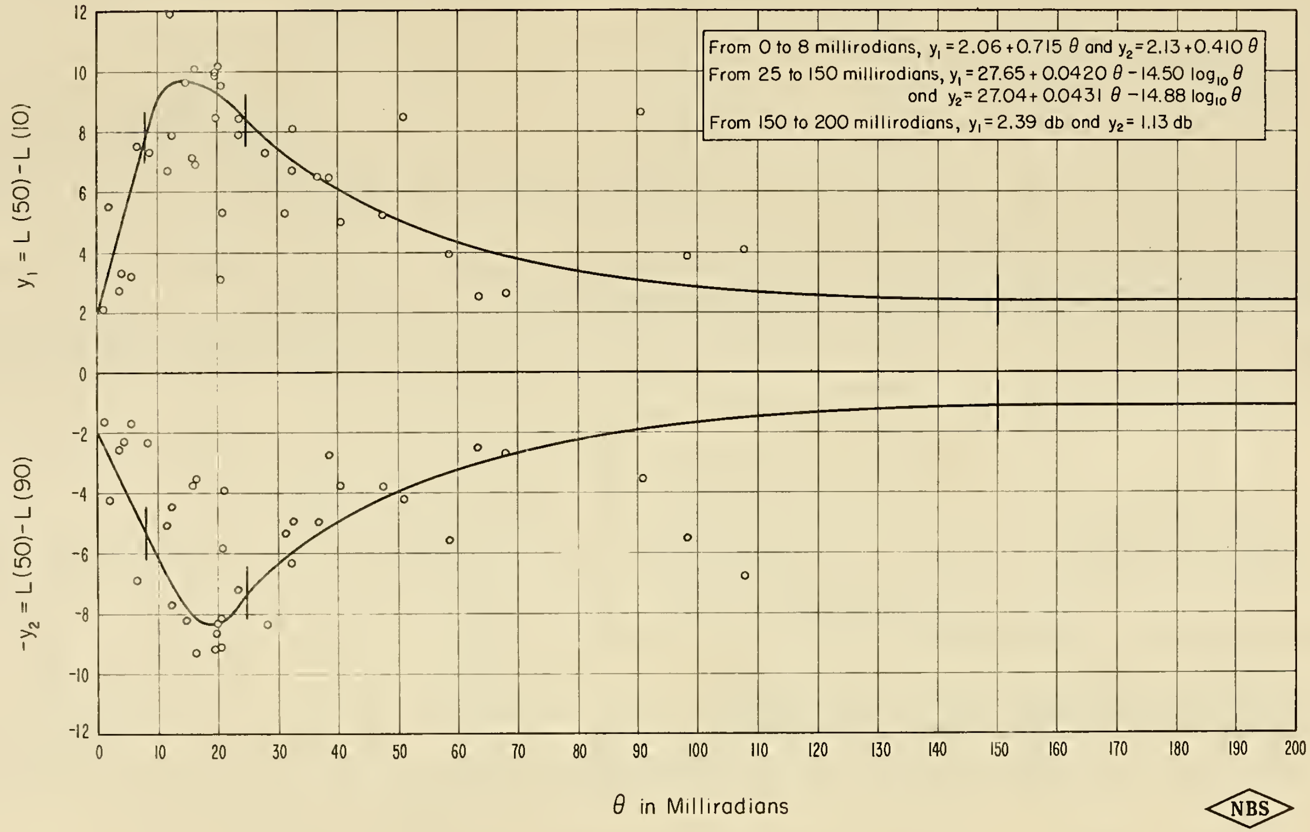


Figure 7

DEVIATIONS OF MEDIAN TRANSMISSION LOSS
$L_{bq}(50)$ AND $L_{bp}(50)$, FROM AVERAGE PREDICTION CURVES

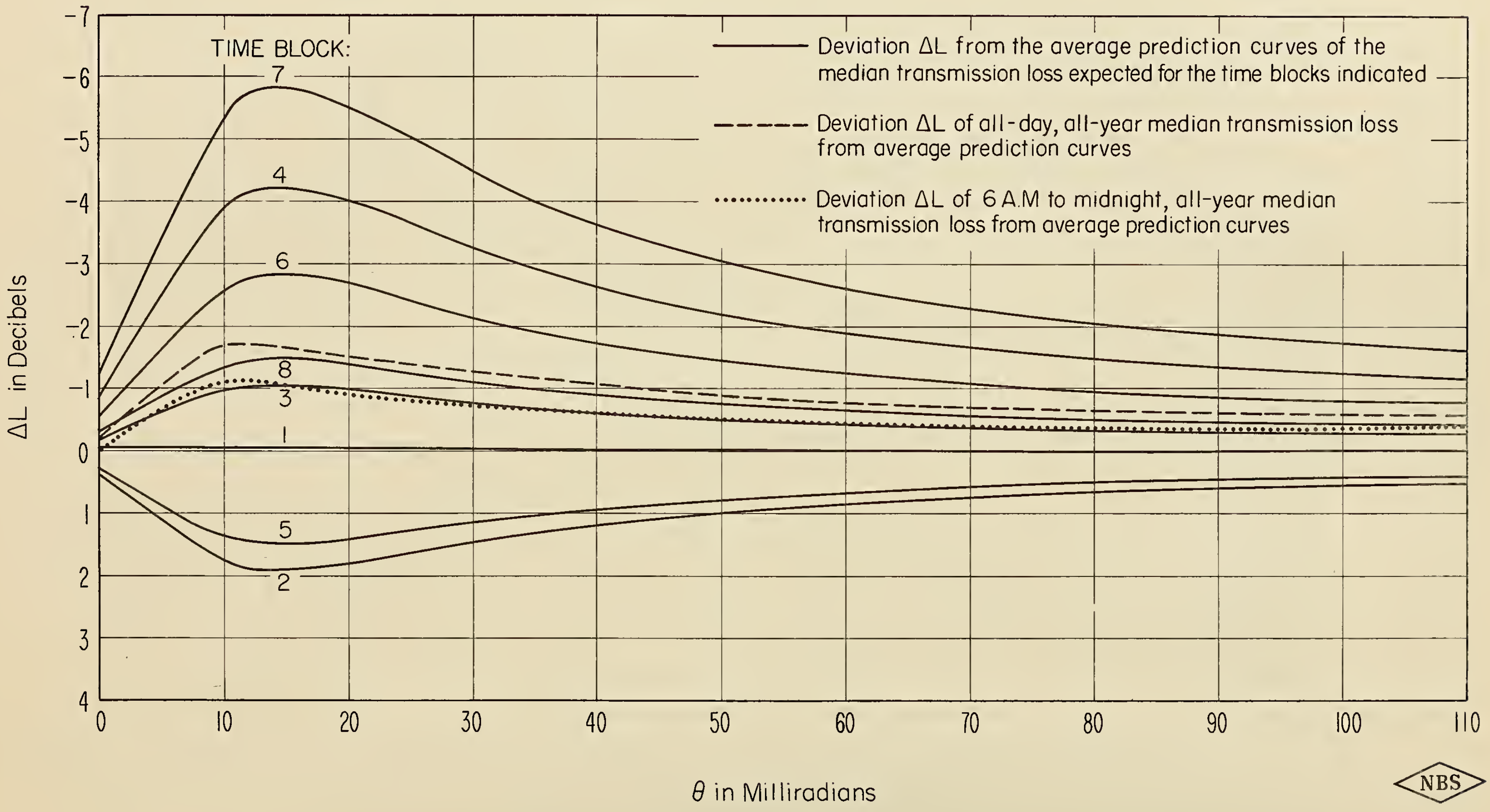


Figure 8

ALL-DAY, ALL-YEAR VARIABILITY OF TRANSMISSION LOSS
VERSUS ANGULAR DISTANCE
AS DETERMINED AT 100 MC

[y(T) = L(50) - L(T) = F(T) - F(50) where T denotes the percentages of time y(T) is exceeded]

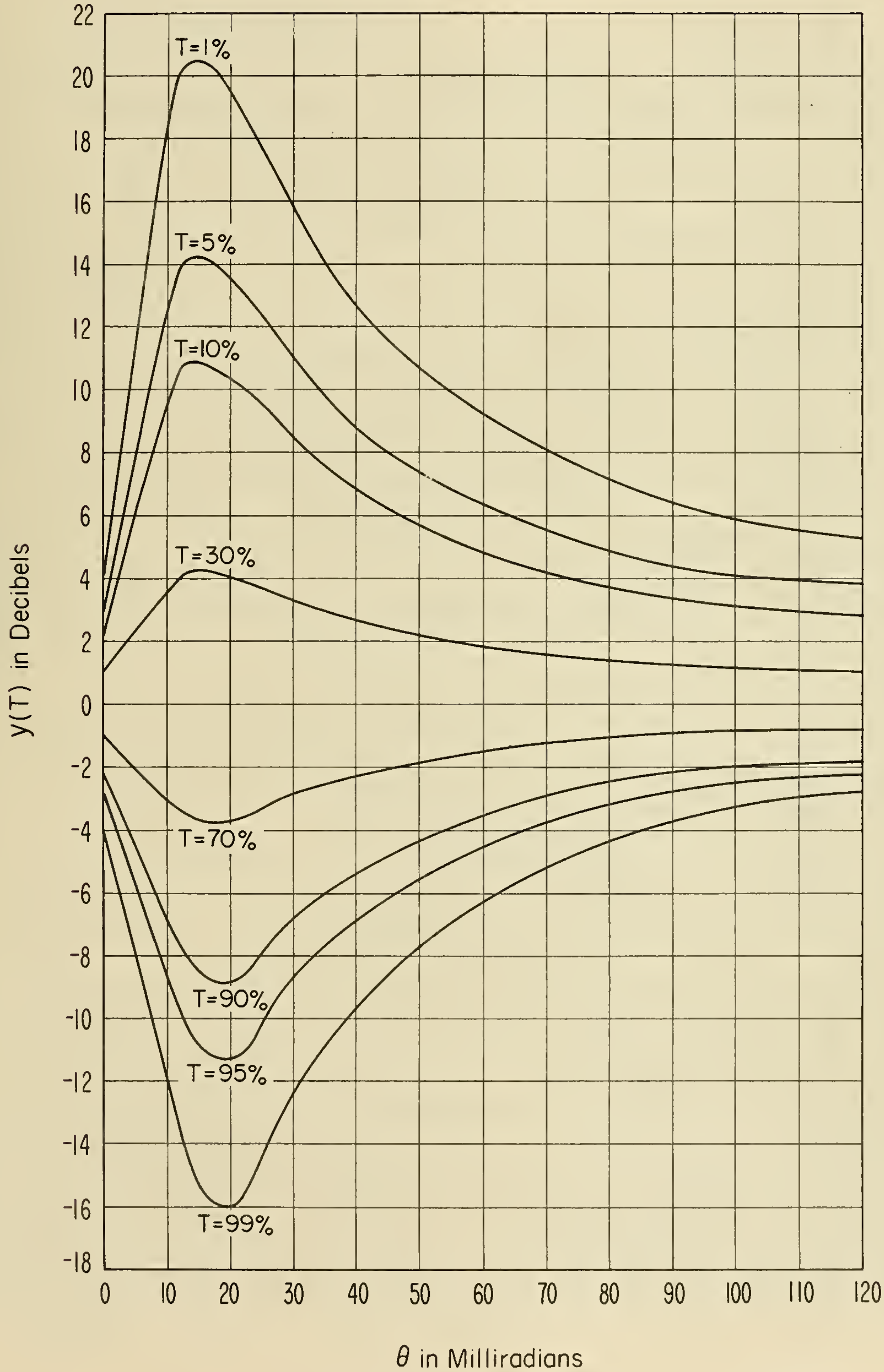


Figure 9

NBS

VARIABILITY OF TRANSMISSION LOSS VERSUS ANGULAR DISTANCE AS DETERMINED AT 100 MC AND CORRESPONDING TO ALL YEAR AND THE PERIOD FROM 6 A.M. TO MIDNIGHT

[y(T)=L(50)−L(T)=F(T)−F(50) where T denotes the percentages of time y(T) is exceeded]

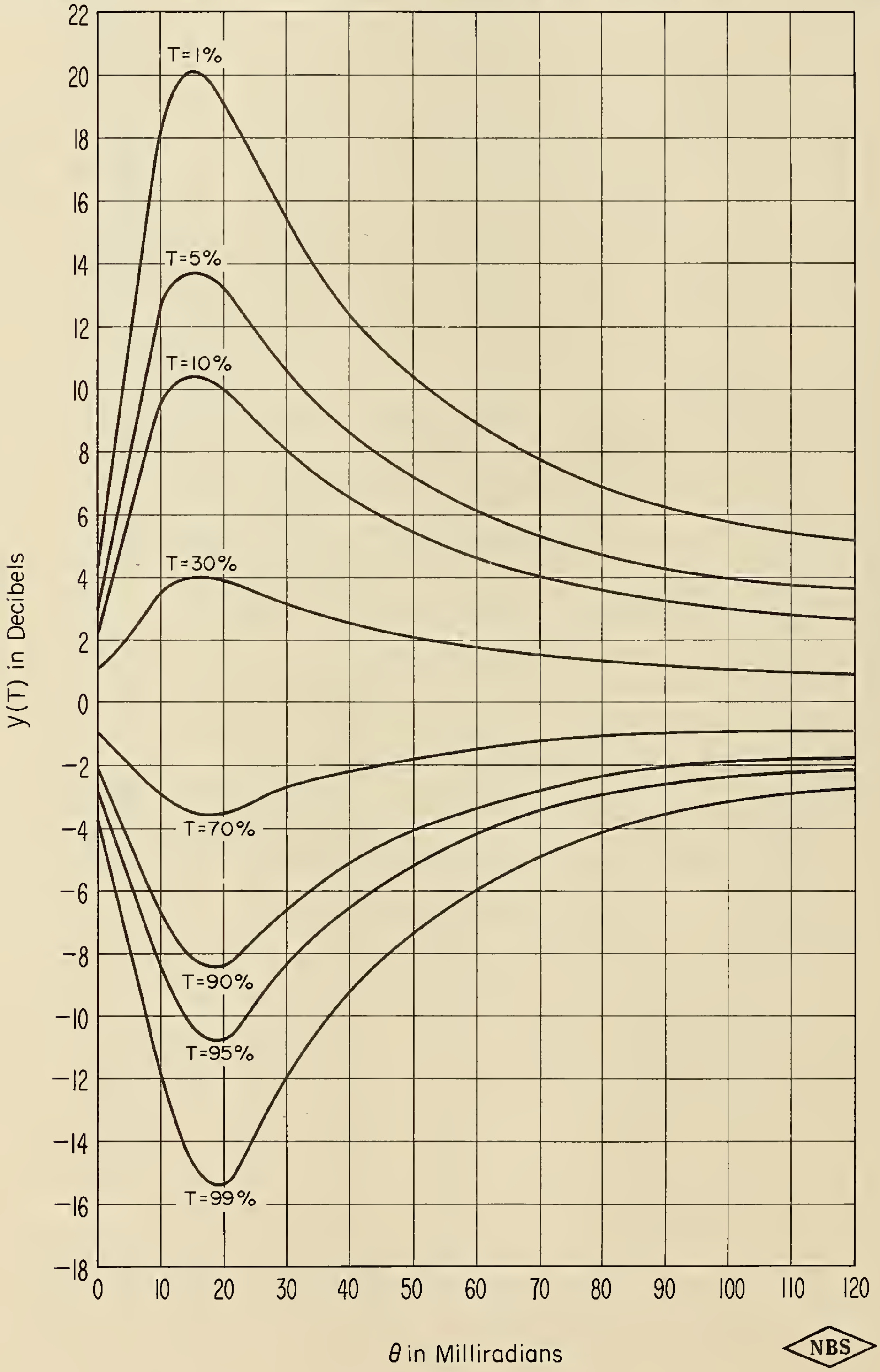


Figure 10

ESTIMATE OF BASIC TRANSMISSION LOSS
AT 100 MEGACYCLES

With One Antenna at 500 Feet and the Other at 30 Feet

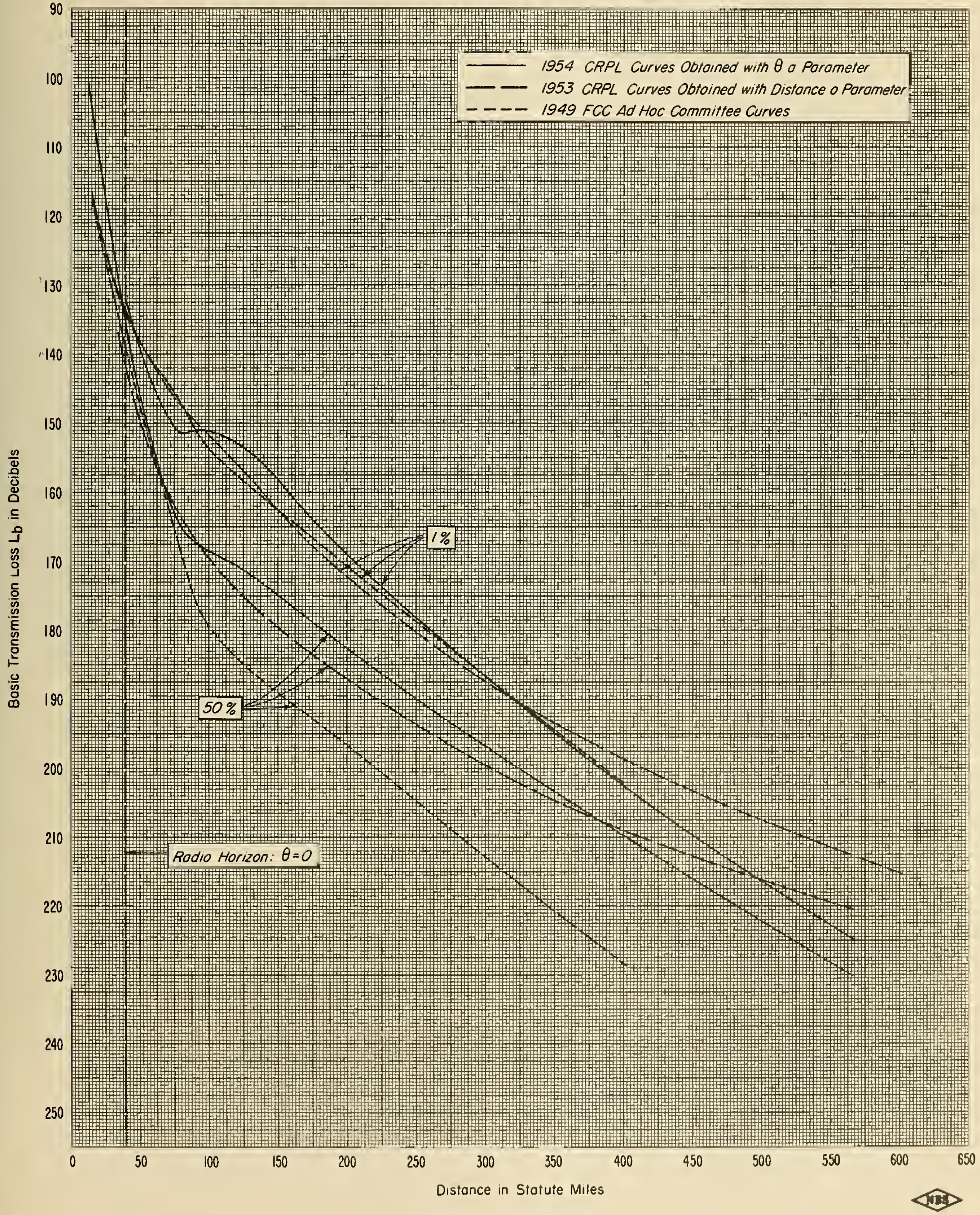


Figure 11

Supplement X

SOME APPLICATIONS OF THE MONTHLY MEDIAN REFRACTIVITY GRADIENT IN TROPOSPHERIC PROPAGATION

By

B. R. Bean and F. M. Meaney
National Bureau of Standards
Boulder, Colorado

See No. 354, page 112p in the list of technical abstracts.

Supplement XI

COMPARISON OF CALCULATED AND MEASURED FIELDS WITHIN THE RADIO HORIZON FOR THE 92 TO 1046 Mc RANGE

By

Albrecht P. Barsis

Supplement XI

COMPARISON OF CALCULATED AND MEASURED FIELDS WITHIN THE RADIO HORIZON FOR THE 92 MC TO 1046 MC RANGE

By

Albrecht P. Barsis
National Bureau of Standards
Boulder, Colorado

SUMMARY

Propagation characteristics of space waves transmitted over irregular terrain may be computed by replacing significant portions of the terrain by a smooth surface, and determining the field by usual methods applicable to such smooth surfaces. The deviation of actually measured fields from the computed values is investigated as a function of Rayleigh's criterion of roughness in the range of frequencies from 92 to 1046 Mc. The data analyzed appear to indicate that Rayleigh's criterion $R = \frac{4\pi \Delta h \sin\psi}{\lambda}$ must be less than 0.1 for the earth to be considered smooth in radio field intensity calculations. Thus, even the relatively smooth terrain encountered in the eastern Colorado plains usually appears to be rough to radio waves with frequencies of the order of 100 Mc and above.

INTRODUCTION

Transmitting and permanent receiving facilities for the Cheyenne Mountain paths have been described previously[1, 2]. The transmission paths from the upper site to receiving sites at Kendrick (49.3 miles), and Karval (70.2 miles) are optical, permitting the use of the 100, 192.8 and 1046 Mc data in conjunction with other, special measurements in order to determine the deviation of measured fields from calculated smooth-earth fields.

In order to obtain additional data, a number of points at about 30 miles distance from the transmitter have been selected, extending in azimuth up to 45 degrees north and south of the center line of the antenna beams (oriented about 105 degrees east of true north). All these points are within the radio horizon of both Cheyenne Mountain transmitting sites, and permit evaluation of the fields by simple ray theory. Measurements at all points have been made on the frequencies of 92, 100, and 192.8 Mc. It is planned to supplement the data by measurements on 1046 Mc as well as frequencies in the 200 to 300 Mc range. Consideration also has been given to measurements in the 40 Mc range. This report presents results obtained on 92, 100, and 192.8 Mc for eleven special points, and on 100, 192.8 and 1046 Mc at Kendrick and Karval.

EQUIPMENT AND PROCEDURE

Fig. 1 shows the truck used for making the measurements at the eleven special points in a typical set-up. Dipole antennas mounted at 30 foot elevation were used to receive the signals from Cheyenne Mountain. They were placed so as to minimize the effects on each other and also to reduce the effect of the truck and mobile engine-generator on the dipole patterns. The signal from the dipoles was fed to receivers through RG-8/U coaxial transmission line. Power to the receivers and auxiliary equipment was supplied through a voltage regulator from an engine generator mounted in a trailer. Calibration of the receivers was accomplished using a Measurements Corporation Model 80 Signal Generator, which had been checked against similar units in the laboratory.

At each point and for each frequency the receiver was first calibrated, then the signal was recorded for a period of about thirty minutes, then the receiver was recalibrated. The signal was recorded by means of an Esterline-Angus graphic ammeter. All recording was performed during daytime hours in December of 1952 and January of 1953.

At each location the antenna match was checked by means of a General Radio Admittance Meter, and the losses introduced by the transmission lines were measured for each frequency. These values were taken into account at the time of analysis of the measurements. For the purpose of analysis of the data, it was assumed that the receiving dipoles (which were always oriented broadside to the transmission path) had the theoretical gain value of 2.15 db relative to an isotropic radiator. The gain of the transmitting antennas toward the various receiving locations was determined from previous computations and measurements performed in part on model antennas.

METHOD OF COMPUTATION

In accordance with the method indicated by K. A. Norton[3] profile graphs were drawn from each of the receiving sites to the transmitters. Fig. 2 shows the profile from the Kendrick fixed site to the Cheyenne Mountain summit transmitter; Fig. 3 shows the profile from Karval to the same transmitter; and Fig. 4 shows profile graphs drawn from four of the eleven special points toward the summit transmitter site. The geometry involved in calculating space wave fields may best be followed by studying Fig. 3, which shows the direct and the ground reflected ray and the grazing angle involved, and gives an indication of the terrain roughness. The Kendrick and Karval profiles were drawn on the basis of standard atmospheric refraction ($k = 4/3$), whereas the profiles on Fig. 4 are based on average atmospheric conditions along the paths for the winter months corresponding to a value of $k = 1.261$. An inspection of Figs. 2 and 3 shows that the terrain between the transmitter and the receiver horizon (neglecting the fact that a small part of Cheyenne Mountain in the vicinity of the transmitter is "seen" by the receiving antennas) is not illuminated by the receiving antennas, and therefore, presumably does not influence the field received at the receiving site. Thus the significant portion of the terrain contributing to the received field is considered to lie between the receiving antenna and its horizon. The terrain in the vicinity of the transmitter, and the directional characteristics of the transmitting antenna are such that no appreciable contribution to the received field would originate from that part of Cheyenne Mountain which is "seen" by the receiving antenna. A second-degree curve was fitted to each profile for a distance extending from the receiving site to a point beyond the receiver horizon by an amount of 10 per cent of the distance between receiver and its horizon. This approach removes any bias in the fitted curve due to the fact that the horizon itself is necessarily an unusually high point of the terrain, although the 10 per cent value itself is arbitrary. The actual fit was done by the method of least squares, taking the actual terrain at sufficiently frequent equally-spaced intervals. The second degree curves representing the least square fit are shown on Figs. 2, 3 and 4.

The profiles shown on Fig. 4 serve to illustrate some of the practical difficulties encountered in this method of analysis. For instance, the second degree curve fitted to the terrain extending from Point No. 3 toward the transmitter site as far as the receiver horizon at nine miles, would not provide a physically realizable solution, as the receiving antenna would be located several feet below the smooth curve representing the terrain, and no reflection off that curve would reach the receiving antenna. A second fit extending only to a closer horizon at 1.5 miles does provide a solution, but the nine-mile horizon itself will undoubtedly produce an additional contribution at the receiving point. On the other hand, it can be shown that the first Fresnel zone for all frequencies includes the entire nine-mile distance, so that it is not feasible to talk of distinct and independent reflections.

For Point No. 5 the horizon appears to be at three quarters of a mile. The profile is virtually the same toward the summit transmitter site (100 and 192.8 Mc) as toward the base site (92 Mc). However, the terrain fit as shown, and computed by the method of least squares does not provide a physically realizable solution on 92 Mc because, due to the lower elevation of the 92 Mc transmitting antenna, the reflection point is pushed out to almost one mile from the receiving antenna, where the terrain fit, as computed, is no longer valid.

Similarly, Point No. 9 does not provide a solution for the 92 Mc field, as the curvature of the fitted smooth curve is such that no reflection will reach the receiving antenna.

For all cases where solutions of the field were obtained by the above method the value of Rayleigh's Criterion of Roughness, R, was obtained. This criterion may conveniently be expressed by the equation:

$$R = \frac{4\pi \;\; \Delta h \;\; \mathrm{SIN}\psi}{\lambda}$$

where ψ denotes the grazing angle, λ the wave length of the signal, and Δh was taken as the root mean square of the deviations of the smooth curve from the actual terrain over the region where the least square fit was obtained.

RESULTS OF COMPARISON OF EXPECTED AND MEASURED FIELDS

Fig. 5 shows the actual deviations of measured from computed fields plotted versus Rayleigh's criterion as defined above. In this graph positive values correspond to measured fields being higher than computed fields. It is immediately apparent that there is no frequency dependence beyond that expressed by the λ in the denominator of the formula used. Although the points appear widely scattered, there is a suggestion of a trend which might be confirmed by additional measurements. A deviation of computed from measured fields of up to two decibels could be expected due to measurements errors, and the limitations of the method of computation. Fig. 5 indicates that only for values of R less than 0.1 is there consistently less than two decibels difference between the computed and measured values. The conclusions to be drawn from this rather limited set of data are, therefore, as follows: only for very smooth terrain with R less than 0.1 may agreement of computed and measured values be expected; and for R between 1 and 2 the expected deviations will increase to the order of ten decibels or more. It may also be concluded that the smooth-appearing terrain of the eastern Colorado plains usually is quite rough to radio waves with frequencies of the order of 100 Mc and above.

REFERENCES

1/ G. R. Chambers, J. W. Herbstreit, and K. A. Norton, "Preliminary Report on Propagation Measurements from 92 to 1046 Mc at Cheyenne Mountain, Colorado," National Bureau of Standards Report 1826, July 23, 1952.

2/ A. P. Barsis, B. R. Bean, J. W. Herbstreit, K. O. Hornberg, and K. A. Norton, "Propagation of Radio Waves Over Land at 1046 Mc (Report for the Air Navigation Development Board)," National Bureau of Standards Report 2494, May 1, 1953.

3/ K. A. Norton, "Transmission Loss of Space Waves Propagated Over Irregular Terrain," Trans. IRE Professional Group on Antennas and Propagation, No. PGAP-3, August 1952.

Figure 1

GEOMETRY FOR SPACE WAVE CALCULATIONS FOR PATH BETWEEN SUMMIT TRANSMITTER SITE AND KENDRICK RECEIVING SITE

RAY PATHS SHOWN ARE FOR 1046 Mc TRANSMISSIONS

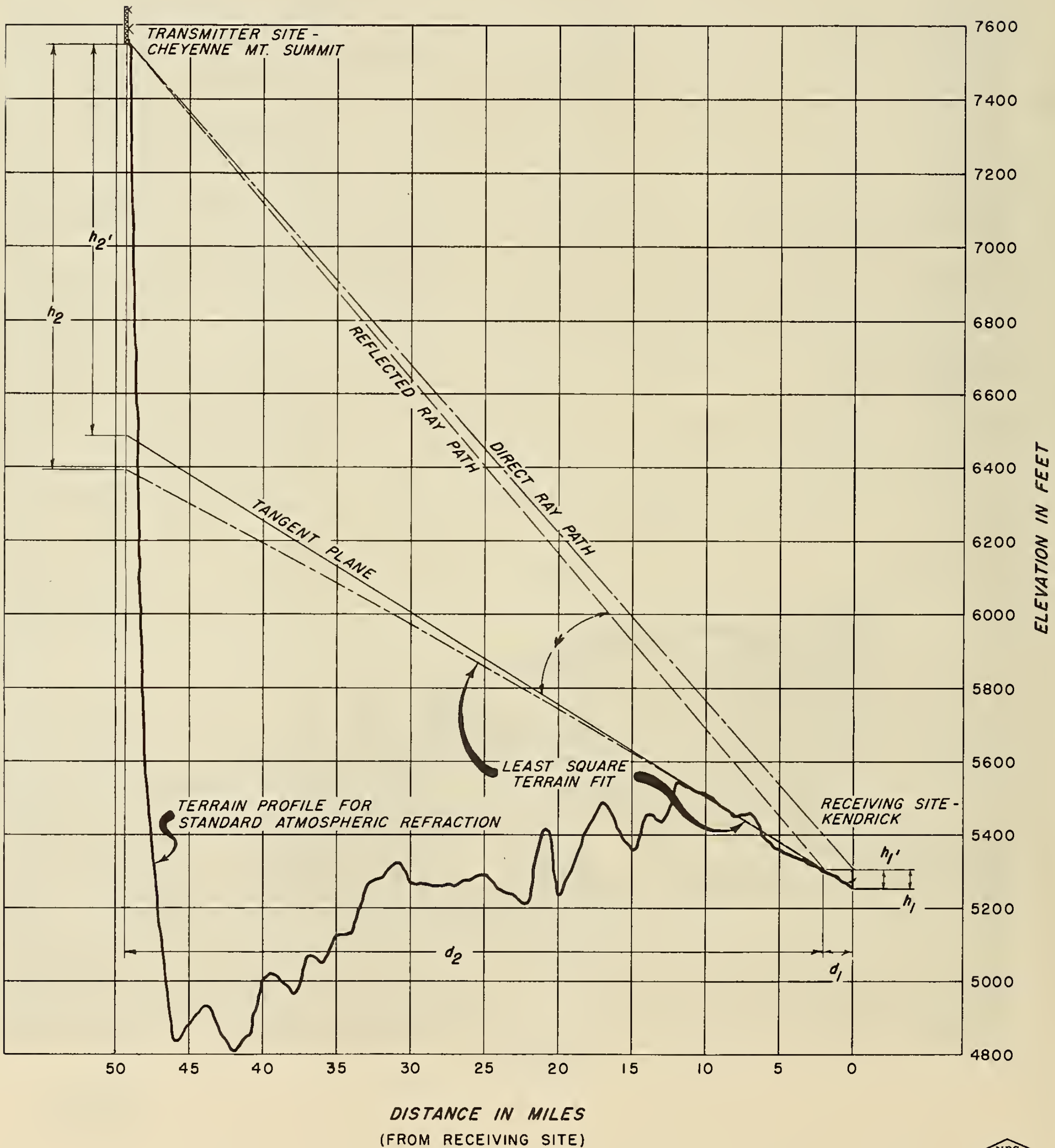


FIG. 2

NBS

GEOMETRY FOR SPACE WAVE CALCULATIONS FOR PATH BETWEEN SUMMIT TRANSMITTER SITE AND KARVAL RECEIVING SITE

(RAY PATHS SHOWN ARE FOR 1046 Mc TRANSMISSIONS)

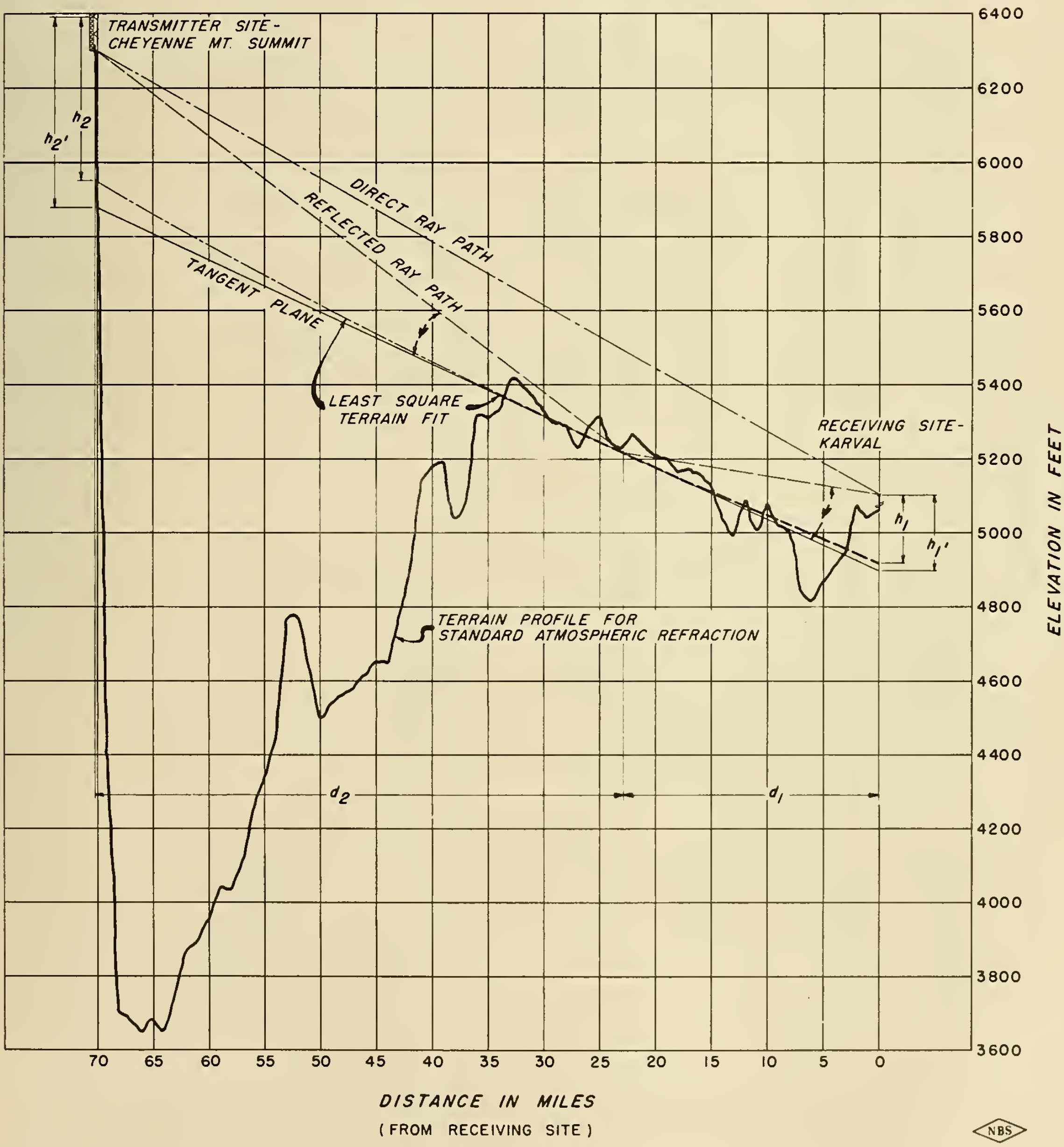


FIG. 3

TERRAIN PROFILES FOR VARIOUS CHEYENNE MT. OPTICAL PATHS

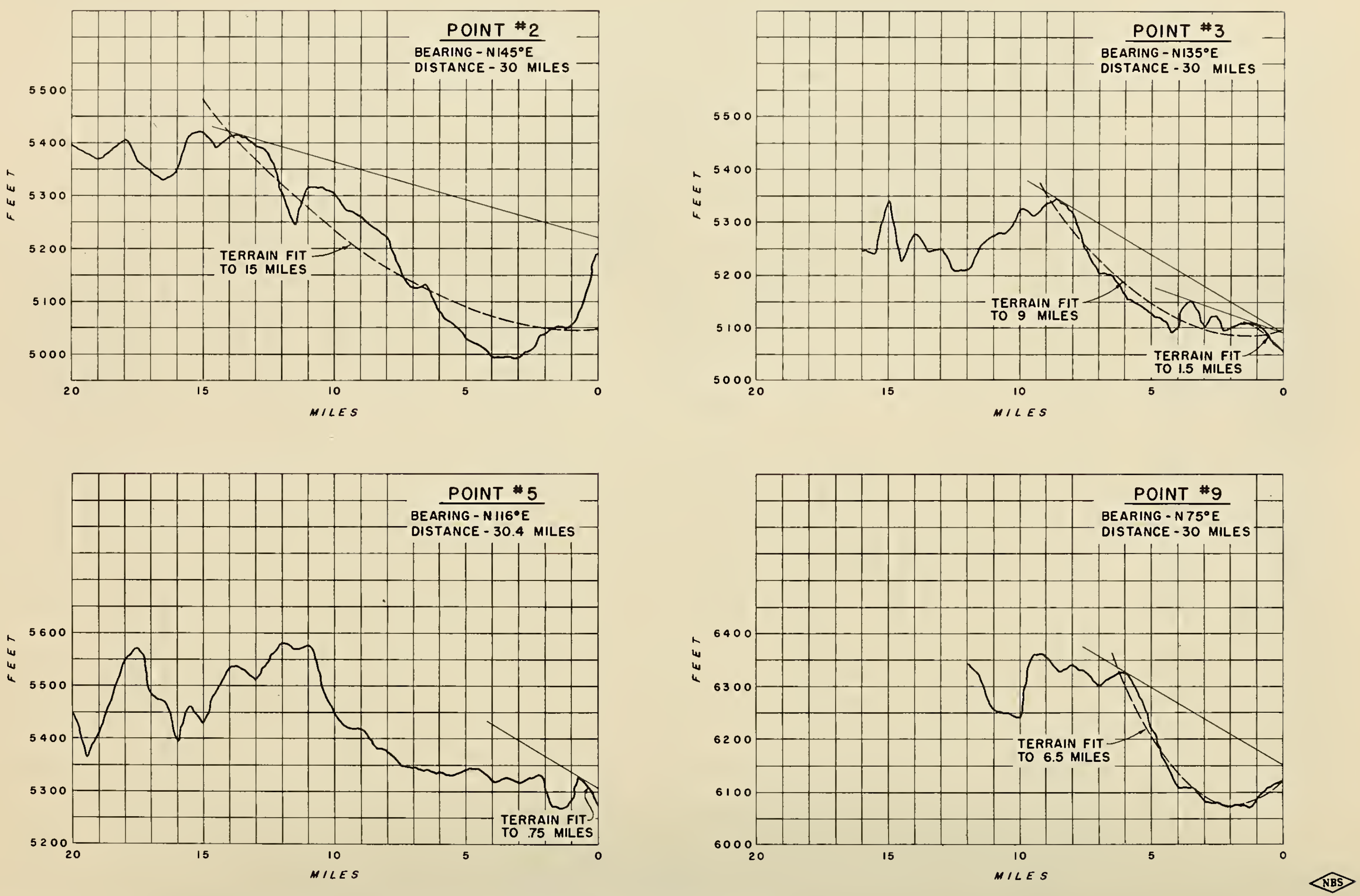


FIGURE 4

CHEYENNE MOUNTAIN OPTICAL PATHS

PLOT OF FIELD DEVIATIONS VS. RAYLEIGH'S CRITERION

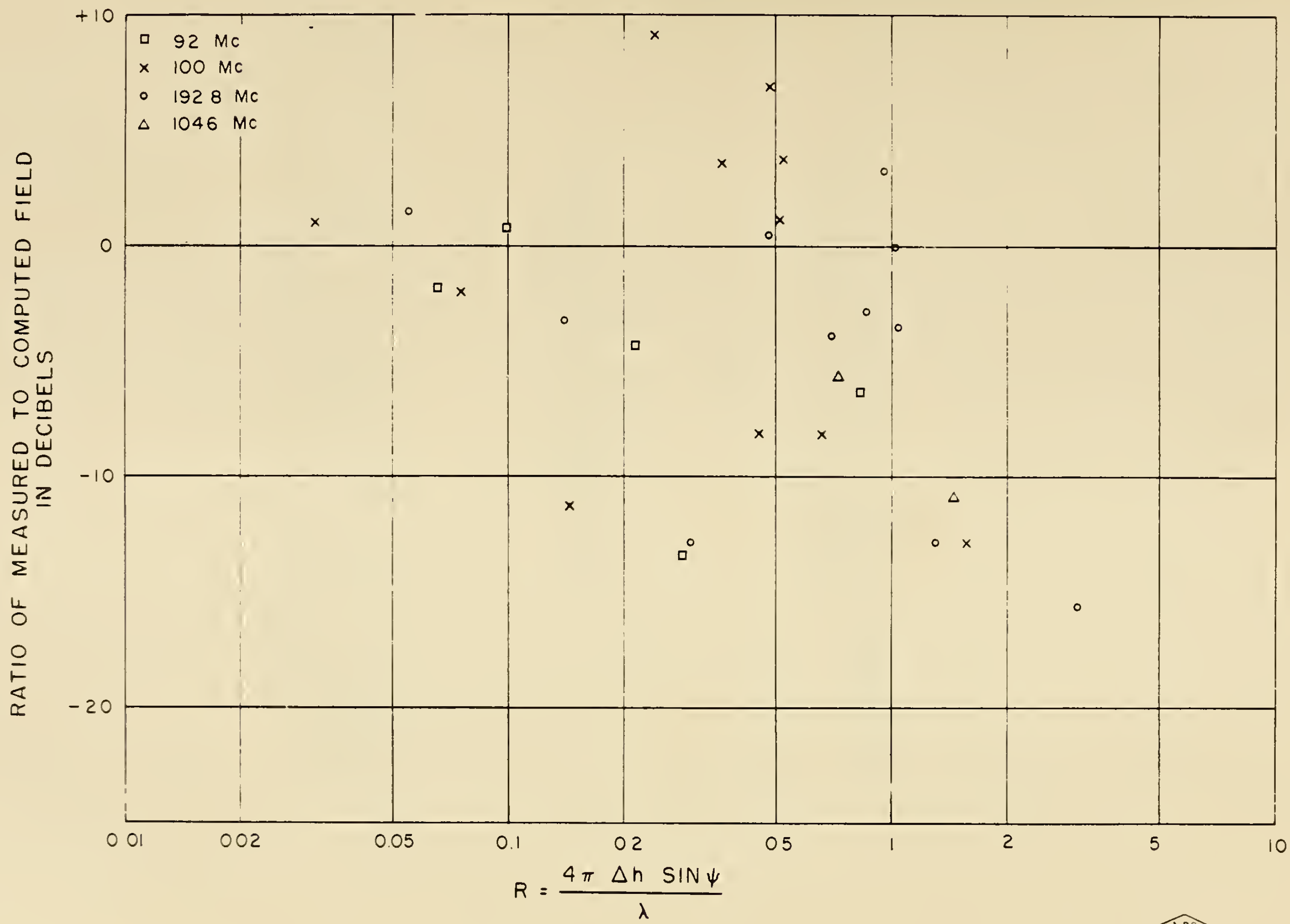


FIG. 5

Supplement XII

AN ANALYSIS OF WITHIN-THE-HOUR FADING IN 100-1000 Mc TRANSMISSIONS

By

H. B. Janes
National Bureau of Standards
Boulder, Colorado

See No. 14, page 10, and also No. 324, page 112f - 112g, "The Rate of Fading in Propagation through a Turbulent Atmosphere," by K. A. Norton, P. L. Rice, H. B. Janes, and A. P. Barsis, in the list of technical abstracts.

Supplement XIII

TREND ANALYSIS AND PREDICTION IN A DISCRETE GAUSSIAN STATIONARY PROCESS

By

H. Staras

Supplement XIII

TREND ANALYSIS AND PREDICTION IN A DISCRETE GAUSSIAN STATIONARY PROCESS

Harold Staras
National Bureau of Standards
Washington, D. C.

SUMMARY

Under the assumption that a discrete time series represents a Gaussian stationary process, this paper derives the maximum-likelihood estimate for the "trend" when no functional form for the trend is known. In addition, this paper obtains the probability distribution associated with a future occurrence.

INTRODUCTION

There are many situations in which physical or chemical theory indicates that there should be a simple relation between two variates X and Y. However, in any actual experiment, experimental errors may enter which make it impossible to measure either X or Y exactly, or sometimes neither can be measured exactly. If the physically indicated relation between X and Y is of the form $Y = f(X; a_1 \ldots a_n)$, where $a_1 \ldots a_n$ represent a set of parameters, then the technique of least squares is commonly used to estimate the parameters $a_1 \ldots a_n$ from a sequence of measured values $\{X_i, Y_i\}$. However, there are many occasions when one observes a time sequence of data $\{Y_i\}$ and it appears that a "trend" exists; yet, no functional form for this trend is known. Under these conditions, many investigators assume some functional form for the trend and then estimate the parameters by the method of least squares. Common functional forms to assume for such a situation are a few terms of a sequence of orthogonal polynomials or a few terms of a Fourier series. Still other investigators may use the method of moving averages 1/ or the linear operator technique 2/. It is the purpose of this paper to point out a new technique for estimating the "trend" in a normally distributed random but auto-correlated sequence.

BASIC CONCEPTS

In this paper, a trend of a correlated random sequence $\{Y_i\}$ is considered to be another correlated random sequence $\{X_i\}$ rather than a well-defined function. The trend sequence $\{X_i\}$, however, has a smaller variance than the measured sequence $\{Y_i\}$ and is more highly auto-correlated than the measured sequence, i.e. the normalized correlation coefficient between X_i and X_{i+k} is greater than the normalized correlation coefficient between Y_i and Y_{i+k} whenever each of them is not zero. Oftentimes this is a more realistic assumption than the assumption that the trend has a well-defined functional form. In particular, this paper investigates the possibility that the measured sequence $\{Y_i\}$ may be considered to be composed of a "trend" sequence $\{X_i\}$ and a purely random sequence $\{\epsilon_i\}$, where the purely random sequence has the characteristics of "white noise." A potentially useful application of this point of view may be the following: Let the measured sequence $\{Y_i\}$ represent hourly median tropospheric field strengths. Let another measured sequence $\{\eta_i\}$ represent an appropriate meteorological parameter. One question of immediate interest is whether or not the two sequences $\{Y_i\}$ and $\{\eta_i\}$ are correlated. Disappointingly, the measured correlation coefficient between the two sequences may turn out to be small, say 0.3. The next question that arises is: "Is it possible that the low correlation between $\{Y_i\}$ and $\{\eta_i\}$ is due to the fact that both sequences contain "white noise?" Furthermore, if it were possible to extract the respective "trend" sequences $\{X_i\}$ and $\{\xi_i\}$ may it not turn out that these two sequences are highly correlated? We next develop a method for estimating the trend sequence, as here defined, from a given measured sequence $\{Y_i\}$ under the assumption that we are dealing with a Gaussian stationary process.

THE POWER SPECTRUM AND THE AUTO-CORRELATION FUNCTION

If the measured sequence $\{Y_i\}$ is sufficiently long, a satisfactory estimate can be made of its auto-correlation function, Ry (k), defined by

$$Ry(k) = \lim_{N \to \infty} \frac{1}{2N+1} \sum_{i=-N}^{N} Y_i \, Y_{i+k}$$

We define the purely random sequence $\{\epsilon_i\}$ to have the following correlation function

$$R_\epsilon(k) = \sigma_\epsilon^2 \ \delta_{k,o}$$

Where δ_{ij} is the Kronecker delta. σ_ϵ^2 is at the moment still unknown. We can estimate it, however, by means of the power spectrum analysis. The power spectrum 3/, $P(\theta)$, for a discrete process is related to the auto-correlation coefficients $R(K)$ by

$$P(\theta) = R(0) + 2 \sum_{k=1}^{\infty} R(k) \cos k\,\theta \qquad (1)$$

Since, by assumption, the process $\{X_i\}$ is independent of the "white noise" $\{\epsilon_i\}$ we have $R_y(k) = R_x(k) + \sigma_\epsilon^2 \ \delta_{k,o}$

Using this relation in (1) we obtain

$$P_y(\theta) = P_x(\theta) + \sigma_\epsilon^2$$

By definition of a power spectrum, $P(\theta)$ must be non-negative for all values of θ between 0 and π. Furthermore, since $R_y(k)$ will become zero and stay zero for k larger than 10 (say) we can actually plot $P_y(\theta)$ as a function of θ. If $P_y(\theta)$ is zero or very nearly so for any value of θ between zero and π, then there is almost no "white noise" in the sequence $\{Y_i\}$. If, however, $P_y(\theta)$ is sufficiently positive for all values of θ (it may look like Fig. 1, for example), then it may be considered to contain "white noise" with a value of σ_ϵ^2 as indicated in the Fig.

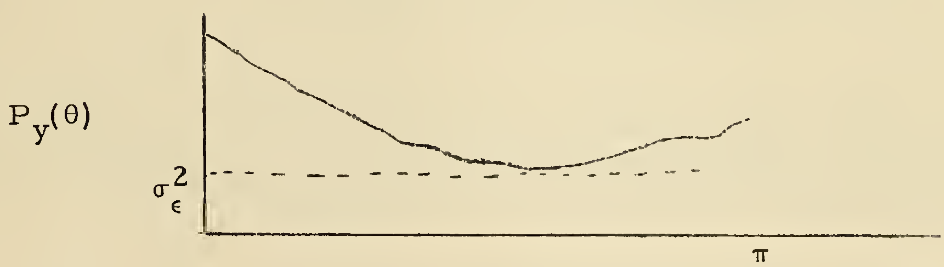


Fig. 1

THE MAXIMUM-LIKELIHOOD METHOD[4]

Having estimated the variance of the purely random component in the sequence $\{Y_i\}$ we are in a position to estimate the trend sequence $\{X_i\}$. If we reduce our data to have a zero mean, the likelihood function for the sequence Y_i is

$$L = \left(\frac{1}{2\pi\sigma_\epsilon}\right)^N \frac{1}{\sqrt{D}} \quad \exp\left\{-\frac{1}{2}\sum_i\sum_j \sigma^{ij} X_i X_j - \frac{1}{2\sigma_\epsilon^2}\sum_i (Y_i - X_i)^2\right\}$$

Where $||\sigma^{ij}||$ is the inverse of the covariance matrix $||\sigma_{ij}||$ which can be obtained simply from $R_x(k) = R_y(k) - \sigma_\epsilon^2\, \delta_{k,o}$ and D is the determinant of $||\sigma_{ij}||$. It should be noted that since $\{Y_i\}$ was assumed to be the Gaussian stationary process, it is natural to expect $\{X_i\}$ and $\{\epsilon_i\}$ to be Gaussian and stationary. The likelihood function is merely the probability density of obtaining what actually was obtained. Under our assumptions, the probability of obtaining the sequence $\{X_i\}$ is

$$\left(\frac{1}{2\pi}\right)^{\frac{N}{2}} \frac{1}{\sqrt{D}} \quad \exp\left\{-\frac{1}{2}\sum_{i,j} \sigma^{ij} X_i X_j\right\}$$

While the probability of obtaining the sequence $\{\epsilon_i\} = \{Y_i - X_i\}$ is

$$\left(\frac{1}{2\pi\sigma_\epsilon^2}\right)^{\frac{N}{2}} \quad \exp\left\{-\frac{1}{2}\sum_i (Y_i - X_i)^2\right\}$$

Since these two probabilities are independent, the likelihood function is as given. The sequence $\{X_i\}$ which maximizes L would be the maximum-likelihood estimate of the trend. To maximize L we take its logarithm and maximize that by the usual method.

$$\ln L = -N \ln 2\pi\sigma_\epsilon - \ln\sqrt{D} - \frac{1}{2}\sum_{i,j=1}^{N} \sigma^{ij} X_i X_j - \frac{1}{2\sigma_\epsilon^2}\sum_{i=1}^{N} (Y_1 - X_i)^2$$

Differentiating with respect to X_k, we obtain

$$-\sum_j \sigma^{kj} X_j + \frac{1}{\sigma_\epsilon^2}(Y_k - X_k) = 0 \qquad K = 1, 2 \text{ ---- } N$$

or

$$\sum_{j=1}^{N} \left(\sigma^{kj} + \frac{1}{\sigma_\epsilon^2}\,\delta_{k,j}\right) X_j = \frac{Y_k}{\sigma_\epsilon^2} \qquad k = 1, 2 \text{ ---- } N$$

Multiplying both sides of the above equation by σ_{ik} and summing over k the results

$$\sum_{k=1}^{N}\sum_{j=1}^{N} \left(\sigma_{ik}\,\sigma^{kj} + \frac{1}{\sigma_\epsilon^2}\,\sigma_{ik}\,\delta_{k,j}\right) X_j = \frac{1}{\sigma_\epsilon^2}\sum_{k=1}^{N} \sigma_{ik} Y_k \qquad i = 1 \text{ ---- } N$$

Performing the summation over k for the left hand side and multiplying both sides by σ_ϵ^2, we obtain

$$\sum_{j=1}^{N} \left(\sigma_\epsilon^2\,\delta_{i,j} + \sigma_{ij}\right) X_j = \sum_{k=1}^{N} \sigma_{ik} Y_k \qquad i = 1, 2 \text{ ---- } N \qquad (2)$$

Thus we must solve a linear set of equations for the Unknown, X_j. Should it be desired to predict the value of a future occurrence, the double sum $\sum_{i,j} \sigma^{ij} X_i X_j$ would be considered to go from 1 to N and N+n, while the sum $\sum_i (Y_i - X_i)^2$ would terminate at N. The linear set of equations to be solved would then be:

$$\sum_{j} \left[\sigma_\epsilon^2 \delta_{ij} + \sigma_{ij} (1 - \delta_{N+n,\, j}) \right] X_j = \sum_{k} \sigma_{ik} Y_k \qquad i = 1, 2 \text{ ---- } N, N+n \quad (3)$$

with Y_{N+n} taken to be zero. The probability distribution associated with a future occurrence at the instant N+n would then be a normal distribution with a mean, X_{N+n}, as determined from the solution of the linear set of equations (3), and a variance equal to σ_ϵ^2.

From the above we see that a solution of one set of linear equations gives all the values of the trend sequence as well as a prediction for the future. This is in contradistinction to the linear operator method[2] which requires, that after solving a linear set of equations, one apply the linear operator to the observed data in order to obtain one term of the trend sequence. One must then reapply the linear operator to obtain each additional term of the trend sequence. In addition, the inherent difficulty with the linear operator method when there are missing data does not apply to the maximum-likelihood method described in this paper.

REFERENCES

1/ M. G. Kendall, "The Advanced Theory of Statistics," Vol. 2 Chap. 30, Charles Griffin and Co., 1946.

2/ N. Levinson, "The Wiener RMS Error Criterion in Filter Design and Prediction," Jour. of Math and Phys. 25, No. 4, Jan., 1947, pp. 261-278.

3/ Herman Wold, "A Study in the Analysis of Stationary Time Series," Chap. 2, Sec. 17, Almquist and Wicksells Boktryckeri A.B., Uppsala 1938. Note that our $P(\theta)$ is Wold's $W^1(x)$.

4/ A. M. Wood, "Introduction to the Theory of Statistics," Sec. 8.3, McGraw-Hill Book Co., 1950.

Supplement XIV

MEASUREMENTS OF MICROWAVE DIFFRACTION OVER TREES

By

J. H. Chisholm

Originally presented at U.S. NEL Symposium, July 25, 1949, NE 120301, Report 173, Problem NEL 1A1, p. 114, U.S. Navy Electronics Laboratory, San Diego, California.

Supplement XIV

MEASUREMENTS OF MICROWAVE DIFFRACTION OVER TREES

By

J. H. Chisholm
National Bureau of Standards
Boulder, Colorado

When the performance of microwave links is calculated from the terrain profile and is compared with the actual performance of such links, it is often found that the actual performance is inferior to the calculated in cases where heavily foliated trees are present in the transmission path. Because many transmission paths, especially in the eastern United States, contain tree foliage to heights of 70 to 100 feet, an investigation to determine quantitatively the effect of such foliage upon microwave propagation was undertaken by the Central Radio Propagation Laboratory. Controlled experiments were conducted over a 4000-ft path at a wavelength of 6 cm; metal screens and actual tree foliage were used as diffracting obstacles.

The experiments sought to determine the nature of the diffraction pattern behind tree-foliage barriers. The experimental approach to the problem was quite simple in that attempts were made to duplicate the classic optical experiment and to secure knife-edge diffraction patterns at the 6-cm wavelength. It should be noted, however, that in the optical case it is assumed that any obstacle in the path is absorbing and that there is no reflection.

It was found that only under certain circumstances could the characteristic knife-edge diffraction pattern be duplicated at 6 cm. In most cases where there was any ground reflection, it was found that instead of a typical single-wave diffraction over a knife edge, a strong interference pattern resulted in the diffracted zone. This interference pattern was quite different from the knife-edge pattern and was characterized by very deep minima. A method of calculation that gave good agreement with the observations considered the signal received behind the knife edge as the resultant of four components. This idea, of course, is not new, but (at microwaves) the general tendency has been to neglect the effect of ground reflection. This gives rise to false results, for there has been found not only a direct wave which is diffracted but, in addition, a wave which is reflected on the transmitter side of the screen and then diffracted. Each of these components, in turn, gives rise to a direct and reflected wave.

Figure 1 shows the results of the initial experiment in which the attempt was made to duplicate the results of the knife-edge optical experiment over a 200-ft path. The dashed curve of figure 1 represents the result derived from simple diffraction theory. The solid and dotted curves were obtained experimentally by running the receiver up and down the tower. The obstacle was a 16- by 50-ft, 18-mil, copper screen. The horns had a beam width of approximately 15 degrees and therefore discriminated almost entirely against ground reflections. However, deep in the diffracted zone, there is a departure from the single diffracted-wave result, and a characteristic interference pattern is apparent. These effects occurred because, at that point, the horn no longer discriminated against the ground wave.

In an effort to determine the magnitude of the ground reflection for the type of terrain (fairly rolling with a high, grassy stubble about 6 to 8 inches high) over which the experiment was conducted, a series of reflection coefficient tests were made. The results of these tests are shown in figure 2. For angles up to 3 and 4 degrees, the effective reflection coefficient varied from 0.6 to 0.95. The reflection coefficient is seen to vary quite rapidly with the change of angle. Little difference is noted, however, between horizontal and vertical polarization for these conditions in which the grazing angles were in most cases less than 4 to 5 degrees.

Figure 3 shows the results obtained for a path in which a wooded area, 400 to 500 feet deep and 60 to 70 feet high, was used as an equivalent dull knife edge. From the illustration it should be noted that again horizontal and vertical polarization give practically the same pattern. There was a slight difference in the spacing and depth of the minima but not enough to be important.

When the experiment was repeated in the presence of a light breeze, the fluctuations in the minima were more pronounced than those in the maxima. When points above the shadow region were investigated, it was noted that the fluctuations due to the leaf motion were less pronounced.

An effort was also made to determine the seasonal effects. On a calm winter day, the characteristic diffraction pattern was again obtained, and found to be only slightly displaced from that observed in the summertime. However, the average signal level was higher.

Again in the presence of a light breeze, the characteristic fluctuation was observed, and upon moving deeper into the diffraction zone, the fluctuations became more rapid. No pronounced difference between horizontal and vertical polarization was noted.

Figure 4 shows a pattern calculated on the four-path basis. A reflection coefficient of 0.8 was used. It may be noted that the characteristic shape of this curve is quite similar to the results obtained by experiment, and does seem to explain very adequately the effect of the reflection. If the reflection coefficient is changed, the depth of these minima is not influenced greatly, but their position is shifted.

A military viewpoint might be taken of the results of the experiments conducted by CRPL. If it were necessary to operate in a severely diffractive region, it might not always be possible to cut down the interfering trees and it might be impossible to install towers to a height of 300 feet. In cases such as these, there always exists the possibility of employing some type of diversity and of determining the optimum antenna spacing experimentally. This method of approach might be of value because of the shifting up and down of the minima.

One other point should be mentioned. As has been shown in the height-gain patterns, the field is very irregular, and a small horn was used. The question may be asked whether or not a large dish in such a field would give the desired gain. As a matter of record, it should be stated that one does not get the desired gain when a dish is used. Experiments along these lines have not been completed but some rather surprising results have been observed.

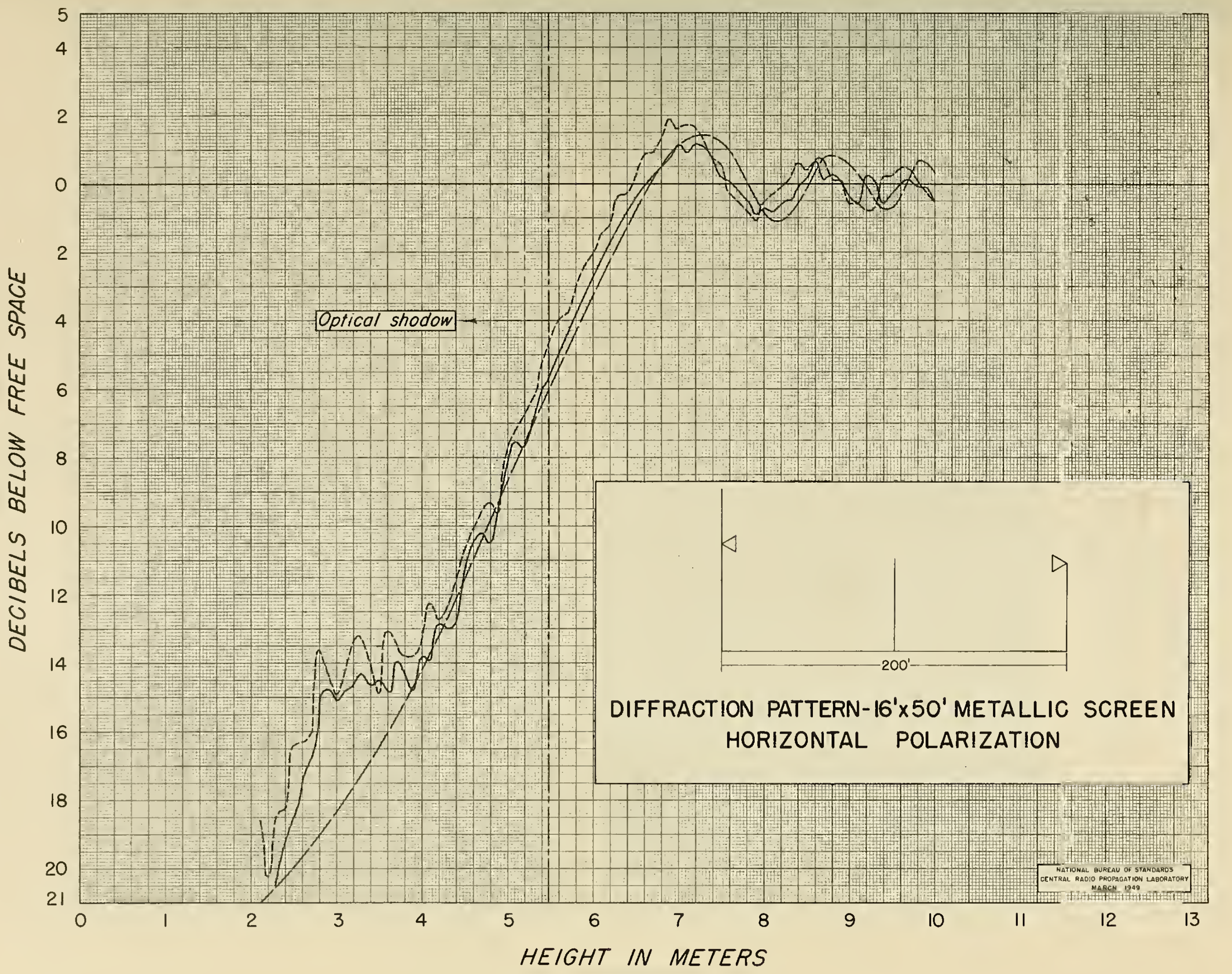

DECIBELS BELOW FREE SPACE
HEIGHT IN METERS
Optical shodow
200'
DIFFRACTION PATTERN-16'x50' METALLIC SCREEN
HORIZONTAL POLARIZATION
NATIONAL BUREAU OF STANDARDS
CENTRAL RADIO PROPAGATION LABORATORY
MARCH 1949

Figure 1

REFLECTION CHARACTERISTICS

200, 500, 1,000 FOOT PATHS GRASSY STUBBLE 4-6 INCHES
VARIATION OF GROUND PROFILE $\leqq \mp$ 1.4 FEET (REF. REC. EL.)
4350 MEGACYCLES

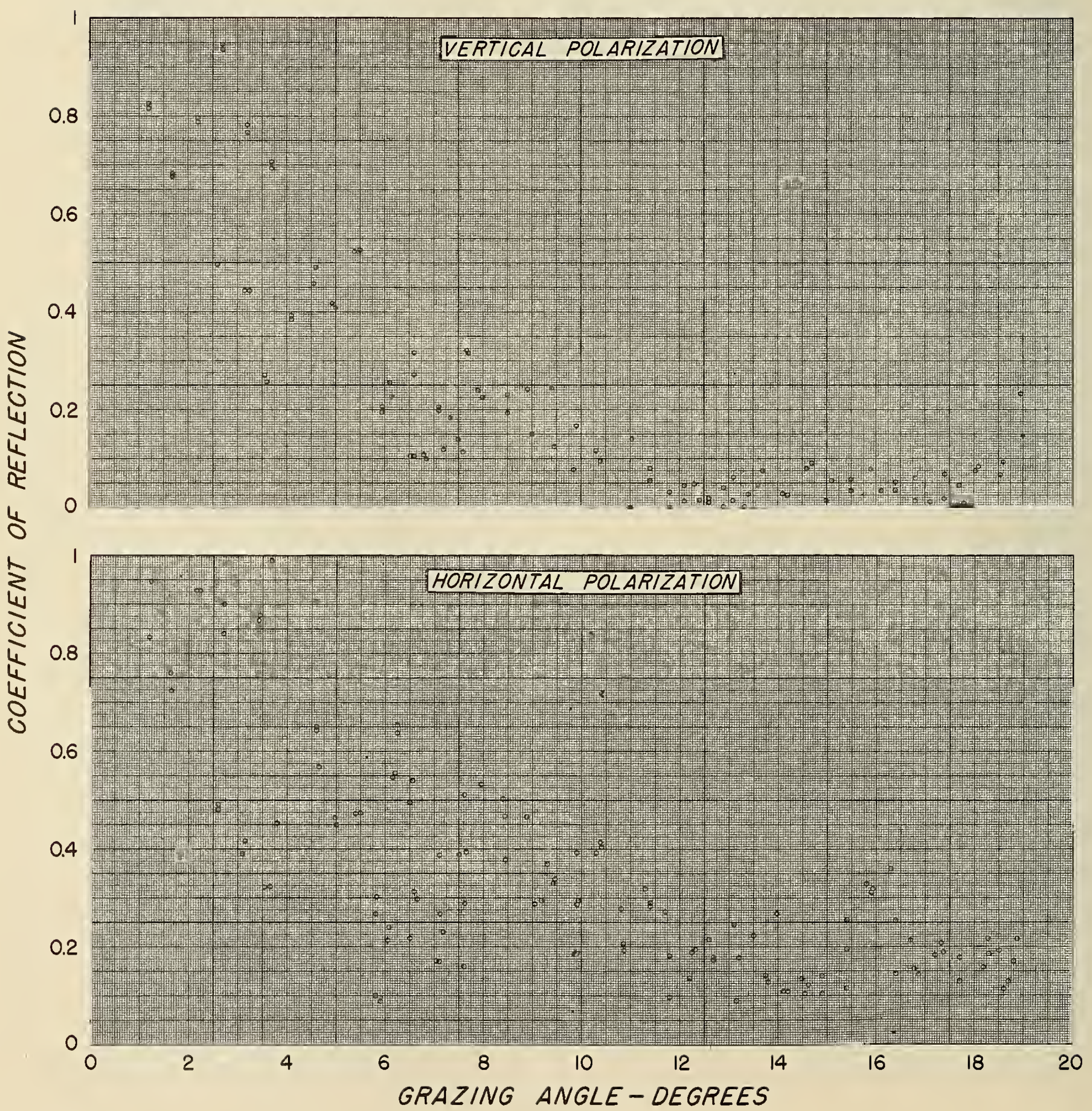


Figure 2

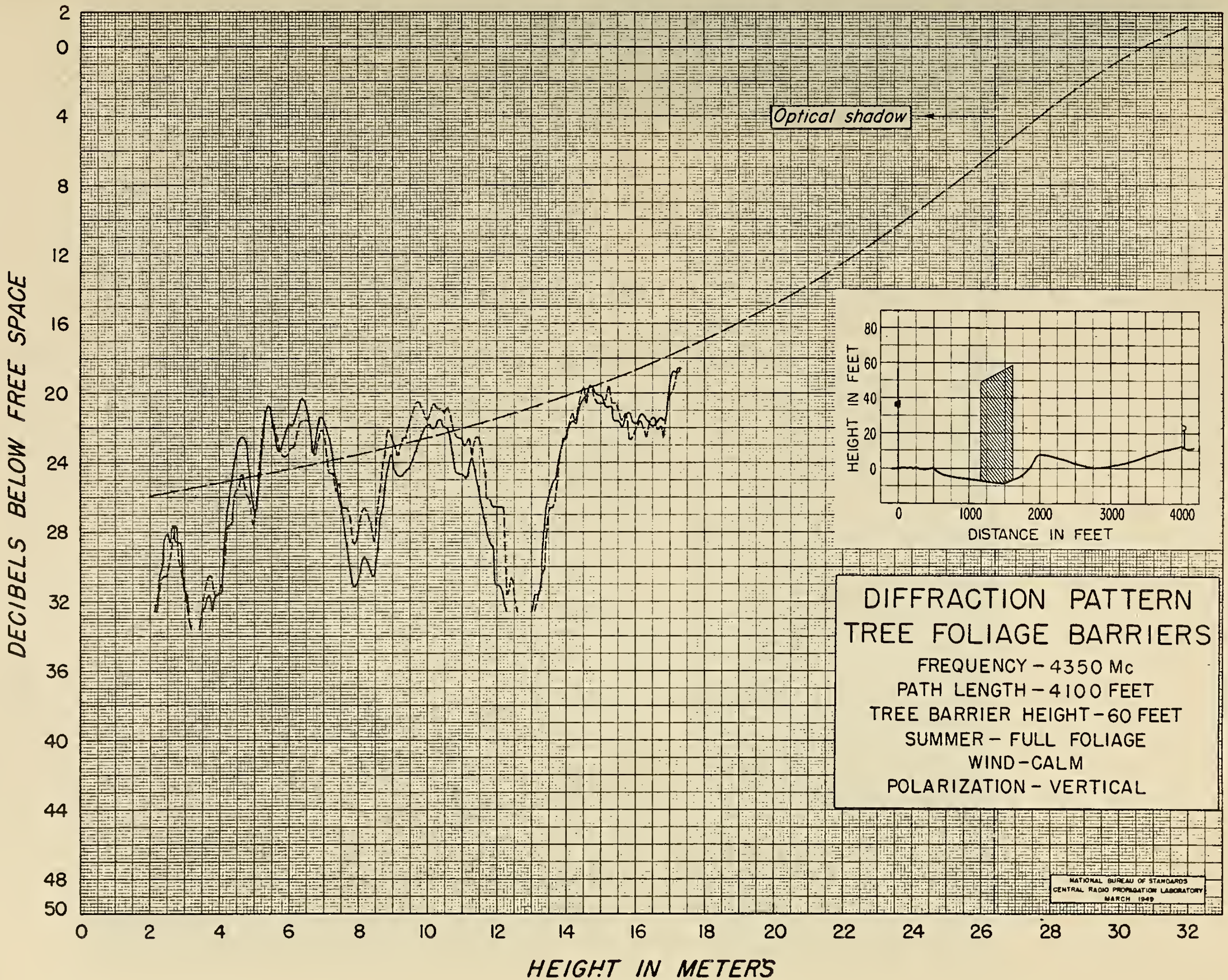

DIFFRACTION PATTERN
TREE FOLIAGE BARRIERS
FREQUENCY - 4350 Mc
PATH LENGTH - 4100 FEET
TREE BARRIER HEIGHT - 60 FEET
SUMMER - FULL FOLIAGE
WIND - CALM
POLARIZATION - VERTICAL
Optical shadow
DECIBELS BELOW FREE SPACE
HEIGHT IN METERS
HEIGHT IN FEET
DISTANCE IN FEET
NATIONAL BUREAU OF STANDARDS
CENTRAL RADIO PROPAGATION LABORATORY
MARCH 1949

Figure 3

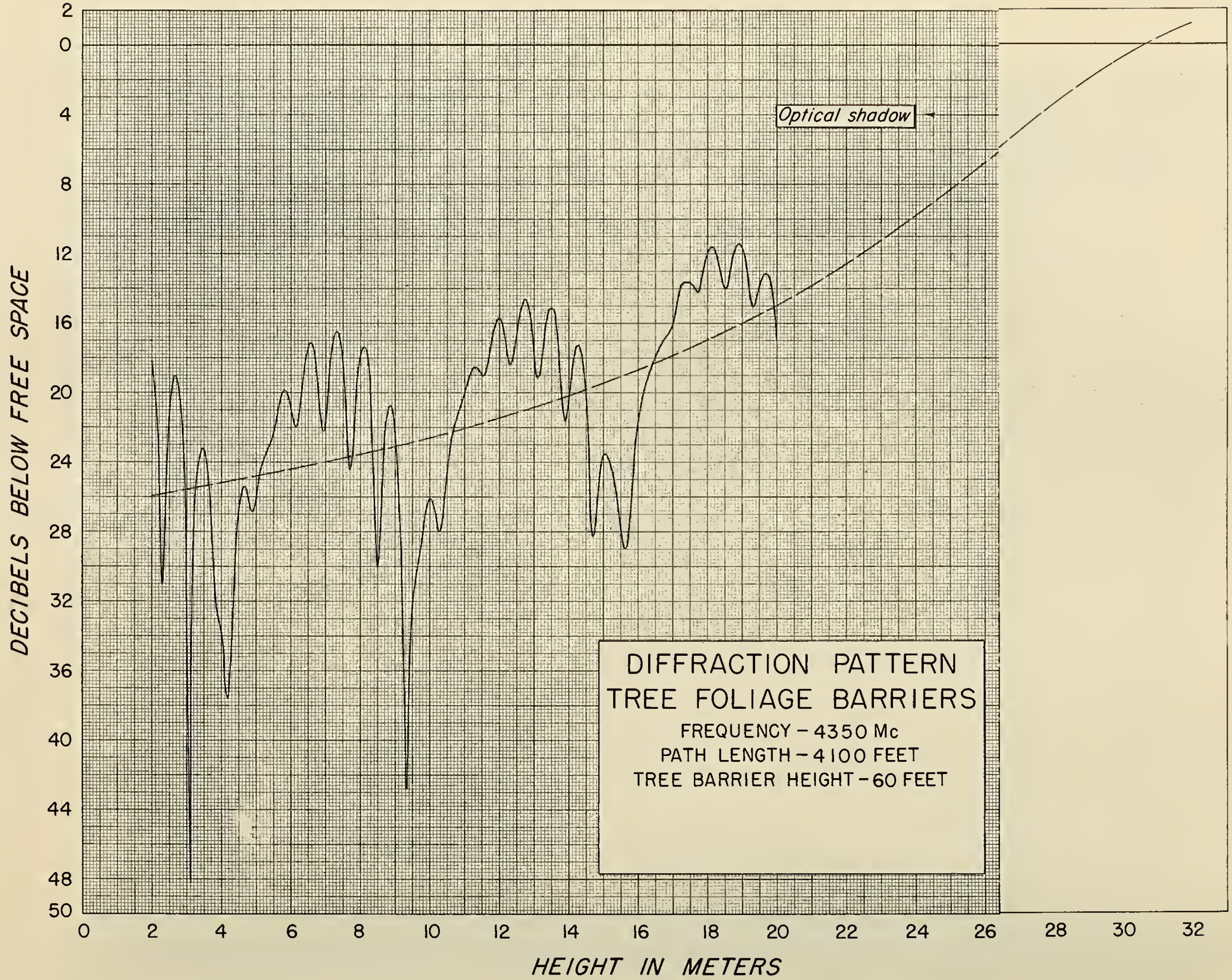

DIFFRACTION PATTERN
TREE FOLIAGE BARRIERS
FREQUENCY - 4350 Mc
PATH LENGTH - 4100 FEET
TREE BARRIER HEIGHT - 60 FEET
Optical shadow
DECIBELS BELOW FREE SPACE
2
0
4
8
12
16
20
24
28
32
36
40
44
48
50
HEIGHT IN METERS
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32

Figure 4

Supplement XV

DEPENDENCE OF THE TRANSMISSION LOSS IN TROPOSPHERIC RADIO WAVE PROPAGATION ON THE ANGULAR DISTANCE

By

Kenneth A. Norton
National Bureau of Standards
Boulder, Colorado

See No. 77, page 35, and also No. 323, page 112f, "The Use of Angular Distance in Estimating Transmission Loss and Fading Range for Propagation Through a Turbulent Atmosphere over Irregular Terrain," by K. A. Norton, P. L. Rice, and L. E. Vogler, in the list of technical abstracts.

Supplement XVI

THE CUMULATIVE PROBABILITY DISTRIBUTION OF THE INSTANTANEOUS RESULTANT AMPLITUDE OF THE VECTOR SUM OF A CONSTANT COMPONENT AND A RANDOMLY PHASED RAYLEIGH DISTRIBUTED VARYING COMPONENT

By

K. A. Norton, P. J. Short, and W. V. Mansfield
National Bureau of Standards
Boulder, Colorado

See No. 108, page 49, and also No. 322, page 112e, "The Probability Distribution of the Amplitude of a Constant Vector Plus a Rayleigh-Distributed Vector," by K. A. Norton, L. E. Vogler, W. V. Mansfield and P. J. Short, in the list of technical abstracts.

Supplement XVII

POINT-TO-POINT RADIO RELAYING VIA THE SCATTERING MODE OF TROPOSPHERIC PROPAGATION

By

K. A. Norton
National Bureau of Standards
Boulder, Colorado

See No. 327, page 112h, in the list of technical abstracts.

Supplement XVIII

PROPAGATION IN THE UHF-TV BAND

By

J. W. Herbstreit

Supplement XVIII

PROPAGATION IN THE UHF-TV BAND*

By

J. W. Herbstreit
National Bureau of Standards
Boulder, Colorado

The propagation factors influencing the performance of TV in either the VHF or UHF portion of the frequency spectrum have been some of the biggest bugaboos in determining the rate of development of a nation-wide TV service in this country. In the case of VHF-TV, the lack of knowledge concerning the propagation factors was responsible for about four years of delay in obtaining a nation-wide TV allocation which is now well on the way to being implemented in the VHF bands. Because of the lack of many operating stations in the upper portion of the spectrum, our knowledge of the propagation factors influencing TV performance in the UHF band is still rather meager; however, it is the purpose of this paper to be informative concerning our present-day knowledge of the propagation factors in the UHF-TV band and to attempt to evaluate them in terms of TV coverage to be expected in the presence of noise and interference.

The Central Radio Propagation Laboratory of the National Bureau of Standards in cooperation with the Department of Defense and the Air Navigation Development Board has been conducting a program of research at frequencies of 418 and 1046 Mc in conjunction with an extensive 100 and 200 Mc program of measurements throughout the United States. The extensive 100 and 200 Mc network of measurements provides us with the best available method of extrapolating our 418 and 1046 Mc measurements to estimate the nation-wide performance on these higher frequencies.

On Fig. 1 are shown the propagation paths over which propagation measurements have been made. Measurements in the VHF bands have been made in the southern portion of the country by the University of Texas, in the northwest by the University of

*Talk presented by Mr. Herbstreit at the IRE National Convention held in New York City March 23-25, 1954.

Washington, in the midwest by the University of Illinois, and the United Broadcasting Company, in the northeast by The Pennsylvania State College, and the Federal Communications Commission has provided data from many of its monitoring stations located throughout the country. The National Bureau of Standards has obtained 418 Mc propagation data from the operation of high power resnatron transmitter by the Collins Radio Company at Cedar Rapids, Iowa and 100, 200 and 1046 Mc data from the NBS operations of the Cheyenne Mountain Field Station. In this program, most emphasis has been placed on obtaining data beyond the radio line of sight; however, the region within the radio horizon has not been neglected.

The type of data collected and the nature of the analyses completed will be illustrated by a series of figures relating to the National Bureau of Standards program of research being conducted at the Cheyenne Mountain Field Station. Fig. 2 illustrates the geographical layout of facilities being used in this program. Transmitters operating on frequencies of 100, 192.8 and 1046 Mc are located at the summit of Cheyenne Mountain at an elevation of 8800 feet above sea level, approximately 3000 feet above the relatively flat plains to the east. Transmitters on 92 and 210.4 Mc are operated at a second site on the mountain at an elevation of 7700 feet. A mobile 100 Mc transmitter has been operated at an elevation of 6200 feet at the base of the mountain and also at the summit of Pikes Peak, elevation 14,110 feet above sea level and 9000 feet above the plains. Field strength recording receivers have been operated at a number of locations at distances ranging from 50 miles out to as far as 616 miles from the transmitters. Reception of all transmissions, including the ones on 1046 Mc, has been found possible at all times at all locations out to and including the 400-mile receiving site at Anthony, Kansas. It may be appropriate to mention that exceptionally high field strength recording system performance is obtained in this program through the use of narrow band techniques. Although the same degree of television system performance would be extremely difficult to achieve because of the much larger bandwidths involved, propagation factors derived from the narrow band system employed in this research program are applicable to television systems. Studies have been conducted of the frequency dependence of propagation from 100 to 1000 Mc, including the attenuation with distance, and the magnitude of signal strength variations as a function of both time and location.

Figure 3 shows sample recording charts of Cheyenne Mountain transmissions on frequencies of 100 and 1046 Mc received at Garden City, Kansas, at a distance of 225 miles from the mountain. Signal strength calibrations are given in terms of basic transmission loss, which is the equivalent propagation path loss encountered between the transmitter and receiver assuming isotropic antennas. Thus, "basic transmission loss" implicitly contains the reduced effective absorbing area of non-directional antennas at the higher frequencies. When going from a VHF frequency of 63 Mc to a UHF frequency of 700 Mc, this amounts to an automatic increase in basic transmission loss of 21 decibels. It may be noted from Fig. 3 that the observed difference in basic transmission loss between 100 and 1046 Mc is about equal to the 20 decibels which would be expected just on the basis of the reduced effective absorbing areas of non-directional antennas for the two frequencies. Another observation which may be made from Fig. 3 is that the rate of fading at the 1046 Mc frequency is approximately ten times that observed at 100 Mc.

Figure 4 illustrates one type of analysis of data which has been conducted for all of the field strength data taken in both the VHF and UHF portions of the spectrum. These particular data are the hourly medians of the 1046 Mc transmission loss taken at Haswell, Colorado, 100 miles from the transmitter during the month of April 1953. The values of loss not exceeded by 10%, 50% and 90% of the measurements are shown as a function of time of day.

In the National Bureau of Standards program of tropospheric propagation research, approximately a quarter million hourly median values of transmission loss have been analyzed for a great variety of frequencies, distance, antenna heights and geographical locations. In these analyses it has been found desirable to express distance in terms of a parameter θ which is defined in Fig. 5 for actual paths under study, as well as for a smooth spherical earth. The terrain profile in the great circle plane between transmitting and receiving antennas is plotted on the basis of an earth radius four-thirds times the actual radius, thereby taking into account standard atmospheric refraction. The angle between lines drawn from the transmitting and receiving antennas tangent to the actual horizons is the angle θ. When θ equals zero, the two horizons coincide a condition commonly termed the line of sight condition. It is seen that θ is also a measure of the scattering region which is thought to be responsible for the existence of signals far beyond the radio horizon. A paper describing the application of the principles of tropospheric scattering was presented at the IRE 1953 National Convention and appears in the 1953 Convention Record. The term "angular distance" for the angle θ is derived from the fact that for a smooth spherical earth it constitutes the distance between horizons expressed in radians.

Fig. 6 shows the results of our analyses of the 100-Mc Cheyenne Mountain data as a function of the angle θ for a wide range of antenna heights, obtained by transmitting from an effective antenna height of only 30 feet at Camp Carson, Colorado and from the top of Pikes Peak. Also shown on this figure is the expected transmission loss versus θ computed in accordance with the diffraction theory in the region of θ less than about 10 milliradians, and in accordance with the tropospheric scattering theory in the region greater than 10 milliradians. It is in the region of 10 milliradians that the scattering mechanism becomes predominant. The degree to which the measured transmission loss agrees with the computed values and the fact that both of these are virtually independent of antenna height when plotted as a function of angular distance, are well illustrated in this figure.

Another propagation factor of importance in television system performance is the variability of tropospherically propagated signals. Fig. 7 shows the results of our analyses of the long-term variability of transmission loss versus θ for the nation-wide 100 Mc study. The ratio between the 10% and 50% fields are given by the upper curve and the ratio of the 50% and 90% are given by the lower curve. The spread between the two curves gives a measure of the variability. It is evident that maximum variability occurs at an angular distance of approximately 18 milliradians which is just beyond the point where the scattered and diffracted fields have become equal as indicated in Fig. 6. Beyond this point the variability becomes less, presumably because the predominant scattering is taking place in a higher, less variable portion of the troposphere. At this time the long-term signal strength variability as a function of frequency in the range 63 to 1000 Mc is assumed to follow the values determined for 100 Mc and depicted by Fig. 6, based principally on our data for the Cheyenne Mountain path which agrees with scattering theory.

In Fig. 8 are shown, as a function of distance in statute miles, the 100-Mc results of the National Bureau of Standards analysis for antenna heights of 500 feet and 30 feet, and for transmission loss levels not exceeded for 1% and 50% of the time. Also shown are the tropospheric propagation curves derived by the Ad Hoc Committee for the FCC in 1949 from the limited data then available. It may be seen that the new and old 1% curves are essentially identical; however, considerable modification is indicated by the new data for the 50% curves beyond about 80 miles, amounting to about 14 decibels at a distance of 125 miles.

Based on the results of our analyses described in the preceding, Fig. 9 shows basic transmission loss versus θ for the TV frequencies at 63 and 700 Mc, and for antenna heights of 30 feet at one end of the path and 50, 500 and 5000 feet at the other end of the path. Again the independence of transmission loss on antenna height may be noted when plotted as a function of angular distance. The frequency dependence is also illustrated, the 700-Mc basic transmission loss in most regions being approximately 20 decibels greater than at 63 Mc.

Fig. 10 shows the same information as Fig. 9, but plotted as a function of distance in miles over a smooth spherical earth rather than in terms of angular distance. While the analysis of data in terms of angular distance is facilitated by reducing the effects of antenna heights and irregular terrain, a plot of transmission loss versus distance re-emphasizes the effects of antenna height as is illustrated here. For example, essentially free-space fields may be expected out to 70 miles at 700 Mc with a very high 5000 ft antenna, while at 63 Mc free-space fields would be expected only to about 20 miles with a similar height antenna. Again the lower loss for 63 Mc is evident in this figure. The curves shown here are for propagation over a smooth spherical earth and additional analyses have been made in order to take into account the effects of irregular terrain.

Fig. 11 shows data relating the median time varying fields to a median location in the presence of irregular terrain. Here the connection with the theoretical median smooth earth basic transmission loss is given for distances beyond line of sight as a function of frequency as derived from our most recent collection of data. Also shown is the correction presented in Reference C of the work of the 1949 FCC Ad Hoc Committee for distances greater than 37.5 miles. It may be seen that our more recent 1000 Mc data indicate that the 1949 correction factor is too severe in this frequency range and the suggested tentative estimate is proposed to replace the original curve at frequencies above 100 Mc.

Fig. 12 shows the terrain correction factor as a function of distance for 63 and 700 Mc for transmitting antenna heights of 500 and 2000 ft. The data shown in Fig. 11 have been used for the region beyond line of sight and the methods used by the FCC Ad Hoc Committee have been used for the region within line of sight.

Up to this point, our latest knowledge of a number of the important propagation factors for VHF and UHF television frequencies has been discussed, including the basic transmission loss versus angular distance, the basic transmission loss versus distance in miles, the variability of transmission loss with time, and the variability of transmission loss with location. The question now arises, what do all these propagation data mean in terms of television servece? Excellent methods were evolved by the FCC Ad Hoc Committee for developing criterea of service from a knowledge of the propagation factors which have just been presented. These methods are contained in Reference E to the FCC Ad Hoc Committee Report and will not be discussed here. However, Fig. 13 has been prepared using these methods and the most recent radio propagation data to determine the relative number of locations receiving acceptable television service on 63 and 700 Mc for at least 90% of the time on the line between two cochannel stations. The following system parameters were assumed in the development of these results: effective radiated power of 100 kw on 63 Mc and 1000 kw on 700 Mc; transmitting antenna heights of 500 feet and receiving antenna height of 30 feet; half-wave dipole receiving antennas with 50 feet of RG 59/U co-axial cable on both frequencies; and the same conditions of signal-to-noise and signal-to-interference ratios to provide satisfactory service as were developed by the FCC Ad Hoc Committee. The required field strength in decibels above one microvolt per meter for 63 Mc is 47 db and for 700 Mc is 75 db. The 28 db difference in required fields for the two frequencies is made up of the 21 db difference in effective absorbing areas of the dipole receiving antennas, 3.4 db difference in noise figure, and 3.6 db additional transmission line loss at 700 Mc. The relative number of receiving locations receiving service is proportional to the height of the curves and the total number of receiving locations is proportional to the total area under them. For each frequency, service is shown for two situations - one corresponding to that limited by noise alone, and the other corresponding to the service obtained on the line between two cochannel stations of equal power and antenna height at geographical spacings specified in the FCC rules for Zone I stations. The small relative number of locations receiving service on UHF is strikingly evident on this figure. Spacing UHF stations only 155 miles apart even reduces this service. If UHF stations were spaced 200 miles apart, the service would essentially return to that limited by noise alone. It is quite evident from the propagation factors alone that, from a "number of locations" standpoint, UHF stations with 500-foot antennas heights will be at a considerable disadvantage with respect to 500 foot VHF stations even though the UHF stations use one megawatt of effective radiated power.

There is a UHF propagation factor that may be taken advantage of to improve this situation. It is the height gain within the line of sight obtained at UHF that was pointed out previously. Fig. 14 shows the same type of information shown in the previous figure, but for transmitting antenna heights of 2000 feet instead of 500 feet. Here it is indicated that the relative number of locations receiving service on UHF with the Zone I 155-mile separation is greater than that obtained on VHF with Zone I 170-mile separation. Again 200-mile separation on UHF would provide the additional service indicated which is essentially limited by noise.

In conclusion, the propagation factors dictate that high power and high antennas are mandatory for UHF to obtain any semblance of equal coverage in the two frequency bands.

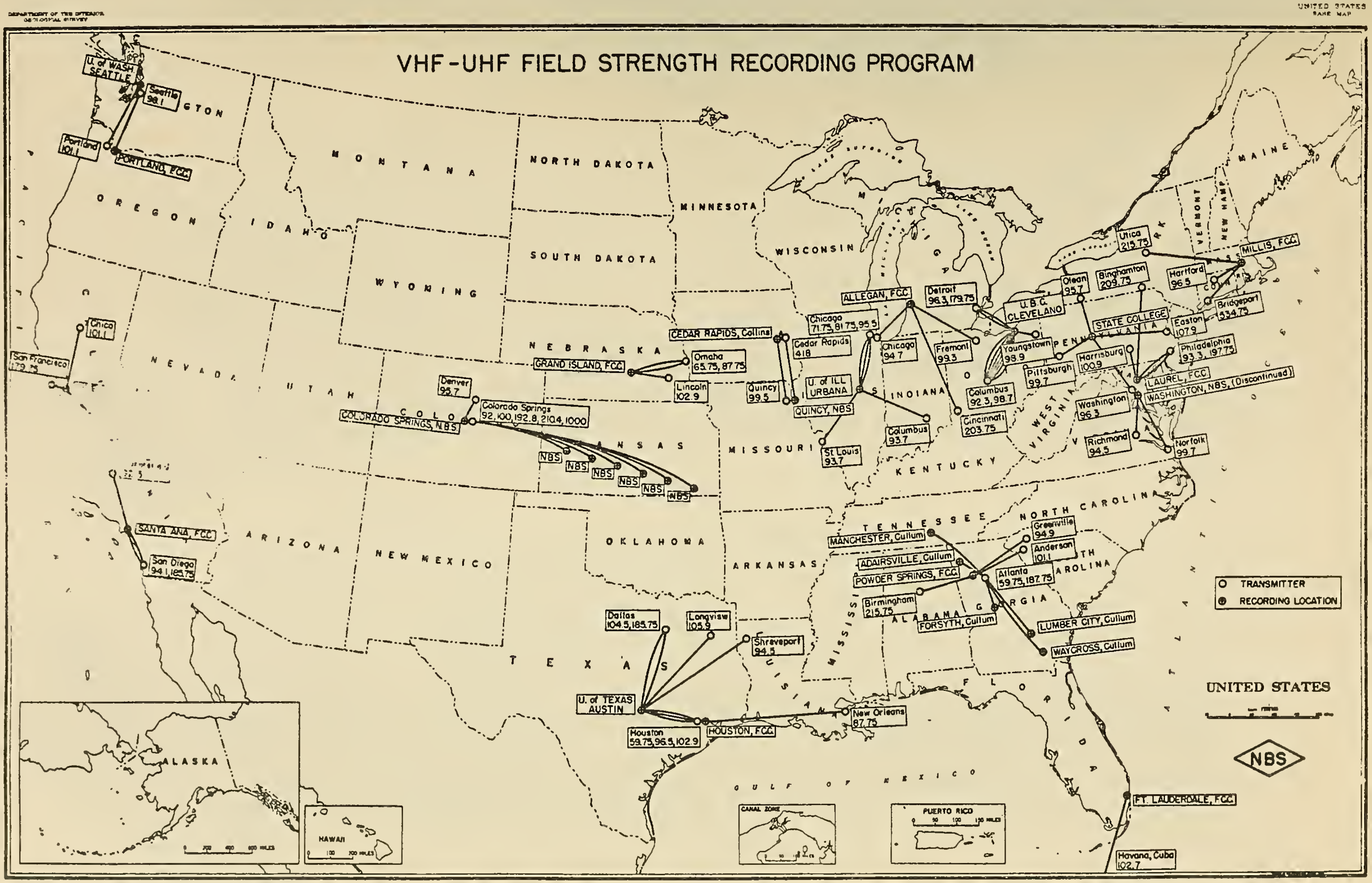

VHF-UHF FIELD STRENGTH RECORDING PROGRAM
U. of WASH SEATTLE
Seattle 98.1
Portland 101.1
PORTLAND, FCC
Chico 101.1
San Francisco 179.75
SANTA ANA, FCC
San Diego 94.1,185.75
Denver 95.7
Colorado Springs 92,100,192.8,2104,1000
COLORADO SPRINGS, NBS
NBS
GRAND ISLAND, FCC
Omaha 65.75, 87.75
Lincoln 102.9
CEDAR RAPIDS, Collins
Cedar Rapids 418
Quincy 99.5
QUINCY, NBS
U. of ILL URBANA
St Louis 93.7
Chicago 71.75, 81.75, 95.5
Chicago 94.7
ALLEGAN, FCC
Detroit 96.3, 179.75
Fremont 99.3
Columbus 93.7
Cincinnati 203.75
Columbus 92.3, 98.7
Youngstown 98.9
U.B.C. CLEVELAND
Olean 95.7
Pittsburgh 99.7
Harrisburg 100.9
STATE COLLEGE
Binghamton 209.75
Utica 215.75
Easton 107.9
Philadelphia 193.3, 197.75
LAUREL, FCC
WASHINGTON, NBS, (Discontinued)
Washington 96.3
Richmond 94.5
Norfolk 99.7
Hartford 96.5
Bridgeport 534.75
MILLIS, FCC
MANCHESTER, Cullum
ADAIRSVILLE, Cullum
POWDER SPRINGS, FCC
Birmingham 215.75
Atlanta 59.75, 187.75
Greenville 94.9
Anderson 101.1
FORSYTH, Cullum
LUMBER CITY, Cullum
WAYCROSS, Cullum
Dallas 104.5, 185.75
Longview 105.9
Shreveport 94.5
U. of TEXAS AUSTIN
Houston 59.75, 96.5, 102.9
HOUSTON, FCC
New Orleans 87.75
FT. LAUDERDALE, FCC
Havana, Cuba 102.7
TRANSMITTER
RECORDING LOCATION
UNITED STATES
NBS
ALASKA
HAWAII
CANAL ZONE
PUERTO RICO
GULF OF MEXICO
MONTANA
NORTH DAKOTA
SOUTH DAKOTA
MINNESOTA
WISCONSIN
OREGON
IDAHO
WYOMING
NEBRASKA
NEVADA
UTAH
ARIZONA
NEW MEXICO
OKLAHOMA
TEXAS
ARKANSAS
MISSOURI
INDIANA
KENTUCKY
TENNESSEE
NORTH CAROLINA
WEST VIRGINIA
ALABAMA
FLORIDA
MAINE
VERMONT
NEW HAMP
DEPARTMENT OF THE INTERIOR GEOLOGICAL SURVEY
UNITED STATES BASE MAP

Fig. 1

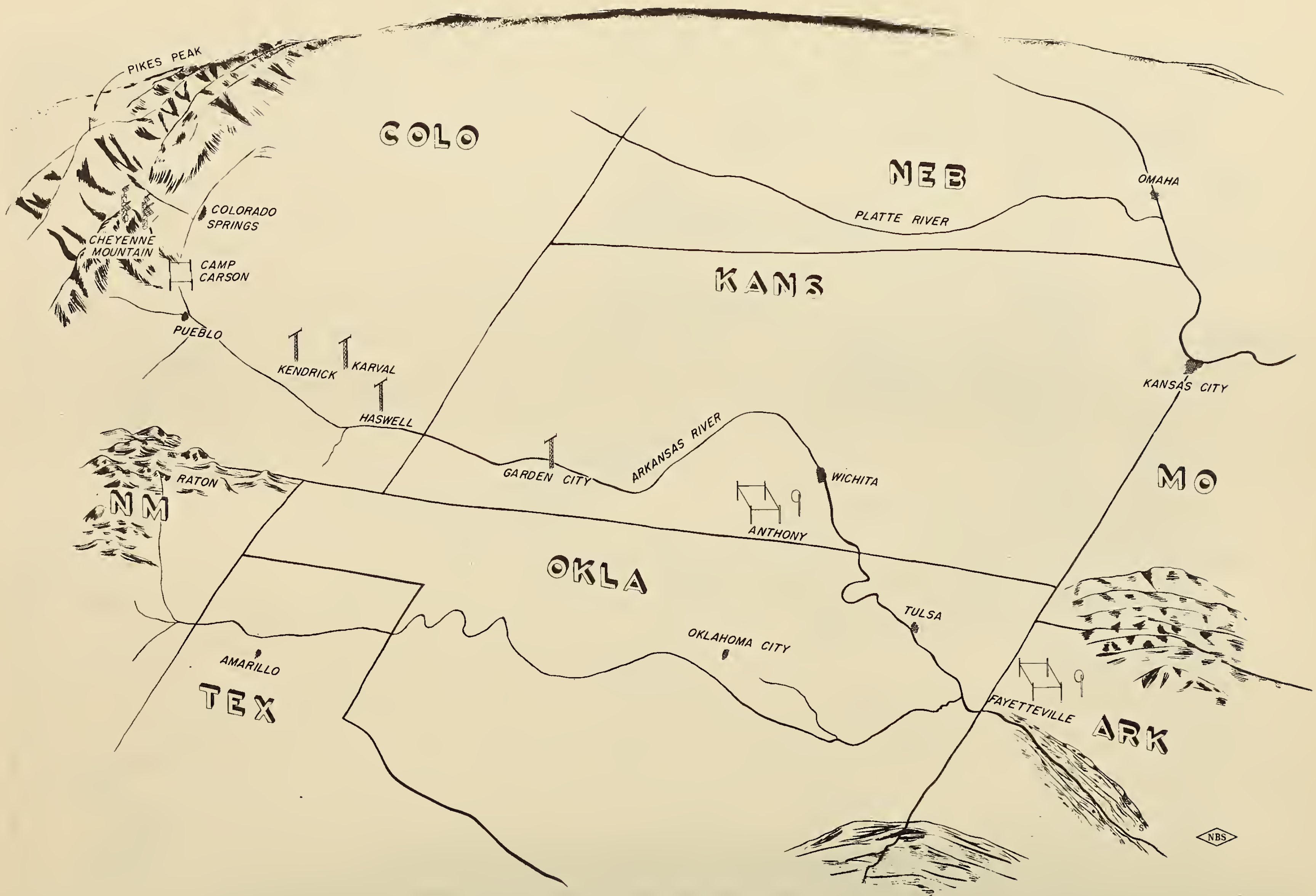

PIKES PEAK
COLO
NEB
OMAHA
COLORADO SPRINGS
PLATTE RIVER
CHEYENNE MOUNTAIN
CAMP CARSON
KANS
PUEBLO
KENDRICK
KARVAL
KANSAS CITY
HASWELL
ARKANSAS RIVER
GARDEN CITY
WICHITA
RATON
MO
NM
ANTHONY
OKLA
TULSA
OKLAHOMA CITY
AMARILLO
FAYETTEVILLE
ARK
TEX
NBS

FIG. 2

SAMPLE RECORDING CHARTS
GARDEN CITY, KANSAS
MARCH 8, 1953

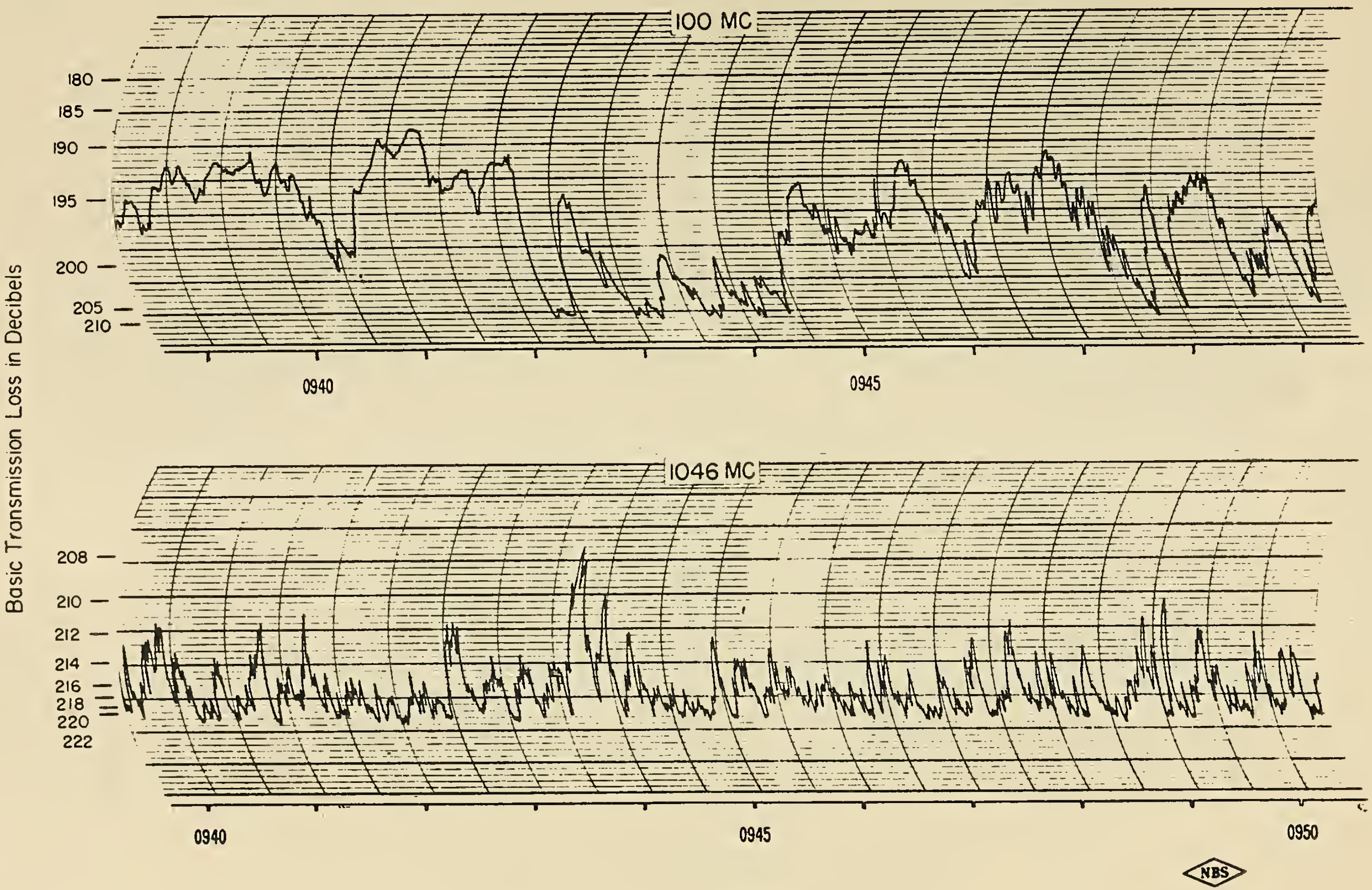
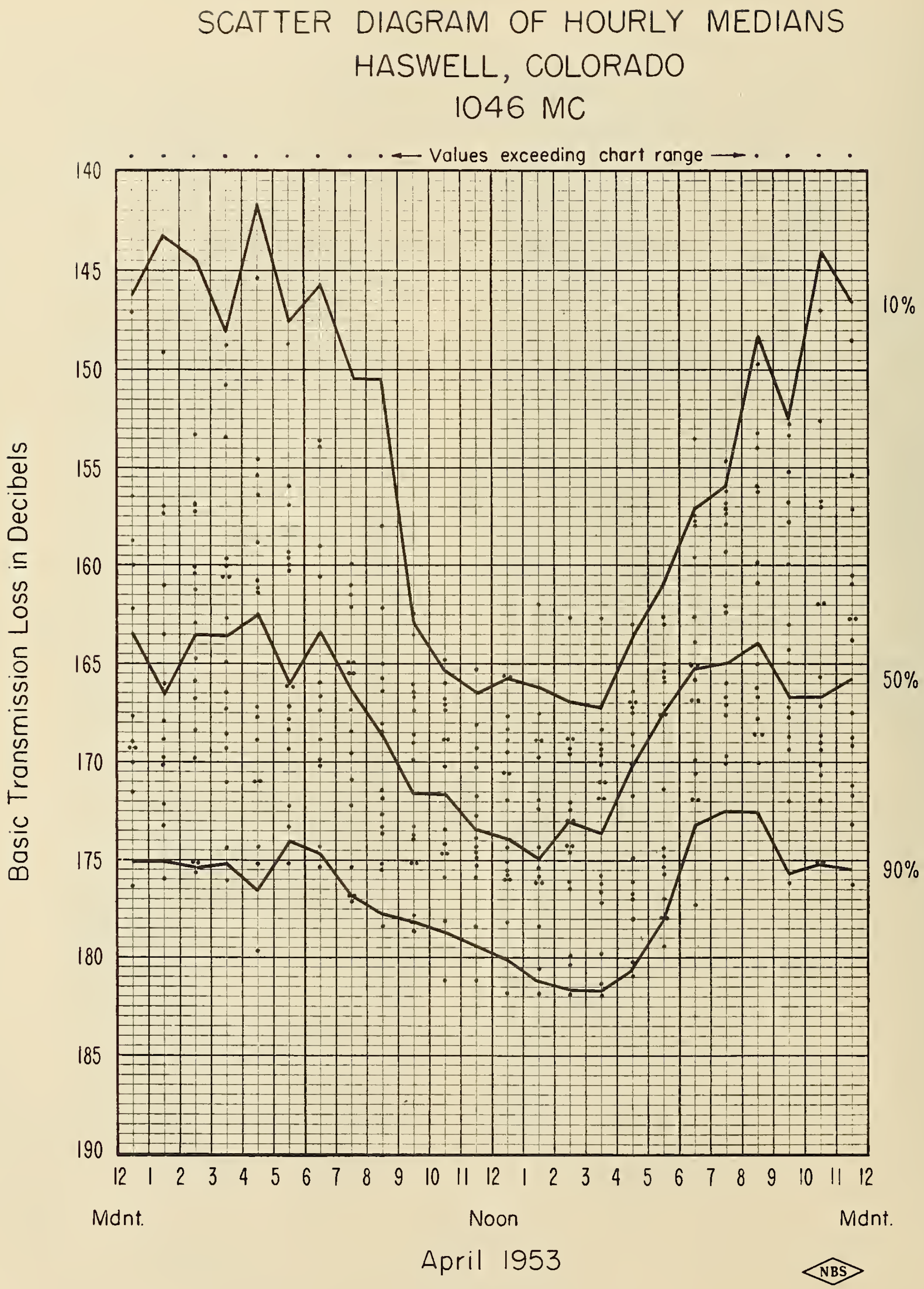


Fig. 3.

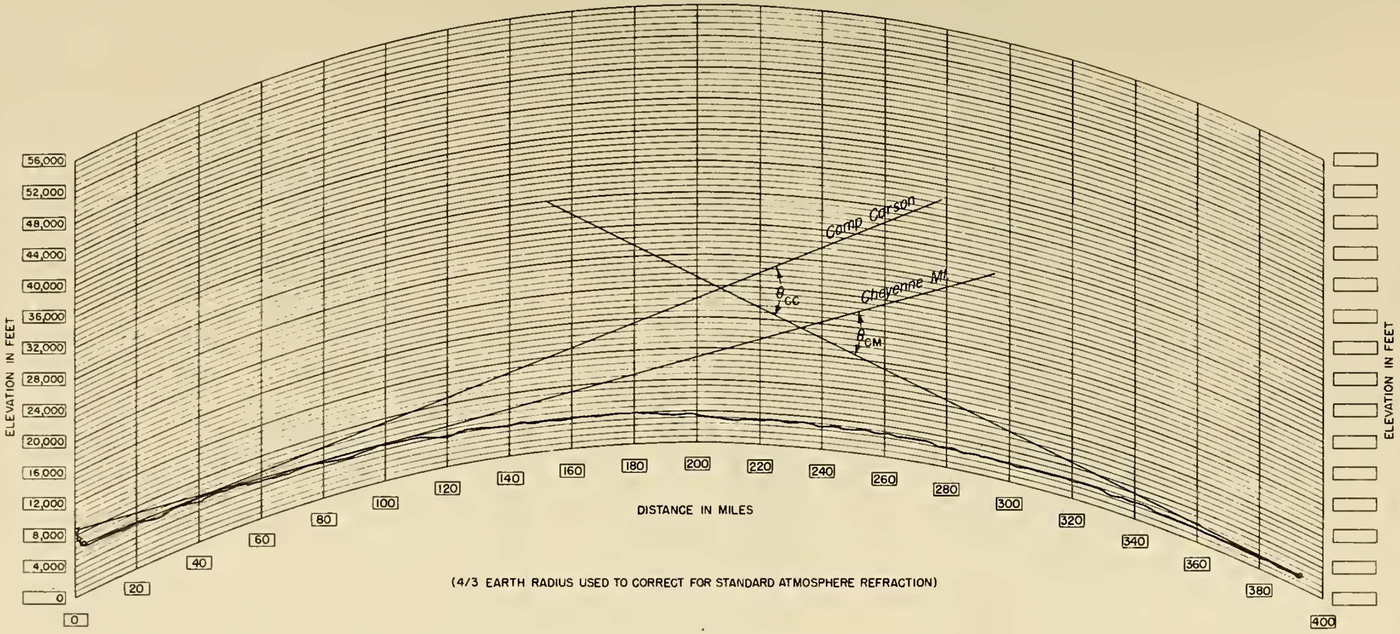


SCATTER DIAGRAM OF HOURLY MEDIANS
HASWELL, COLORADO
1046 MC
← Values exceeding chart range →
Basic Transmission Loss in Decibels
140
145
150
155
160
165
170
175
180
185
190
10%
50%
90%
12 1 2 3 4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
Mdnt.
Noon
Mdnt.
April 1953
NBS

Figure 4

THE PARAMETER θ IN TROPOSPHERIC PROPAGATION

ACTUAL PATH CHEYENNE MT AND CAMP CARSON TO ANTHONY



DERIVATION OF θ FOR SMOOTH EARTH

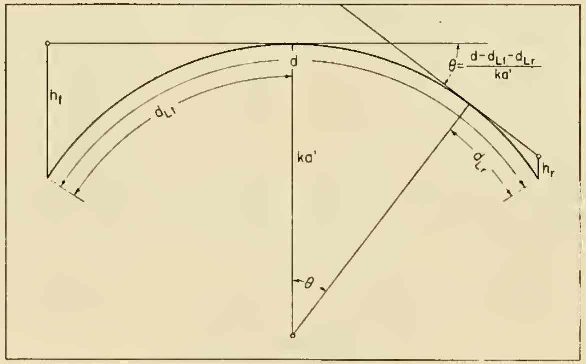
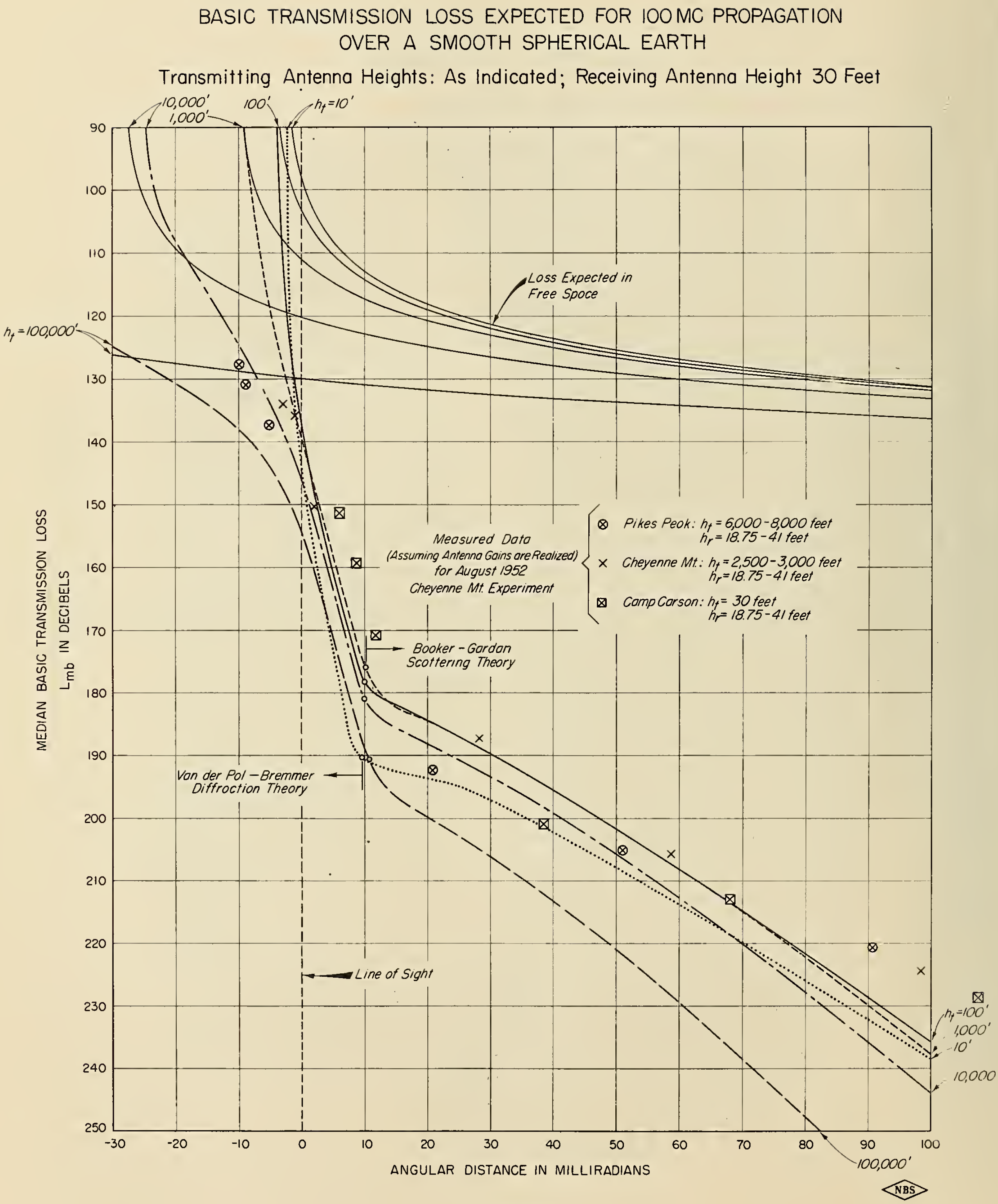


Figure 5



BASIC TRANSMISSION LOSS EXPECTED FOR 100 MC PROPAGATION
OVER A SMOOTH SPHERICAL EARTH
Transmitting Antenna Heights: As Indicated; Receiving Antenna Height 30 Feet
10,000'
1,000'
100'
h_t=10'
h_t=100,000'
Loss Expected in Free Space
Measured Data
(Assuming Antenna Gains are Realized)
for August 1952
Cheyenne Mt. Experiment
Pikes Peak: h_t = 6,000-8,000 feet
h_r = 18.75-41 feet
Cheyenne Mt.: h_t = 2,500-3,000 feet
h_r = 18.75-41 feet
Camp Carson: h_t = 30 feet
h_r = 18.75-41 feet
Booker - Gordon Scattering Theory
Van der Pol — Bremmer Diffraction Theory
Line of Sight
h_t=100'
1,000'
10'
10,000'
100,000'
MEDIAN BASIC TRANSMISSION LOSS
L_{mb} IN DECIBELS
90
100
110
120
130
140
150
160
170
180
190
200
210
220
230
240
250
-30
-20
-10
0
10
20
30
40
50
60
70
80
90
100
ANGULAR DISTANCE IN MILLIRADIANS
NBS

Figure 6

AVERAGE VARIABILITY OF TRANSMISSION LOSS VERSUS ANGULAR DISTANCE
AS DETERMINED AT 100 MC

DIFFERENCES BETWEEN 10% AND 50% FIELDS AND 50% AND 90% FIELDS
AS A FUNCTION OF THE ANGULAR DISTANCE θ

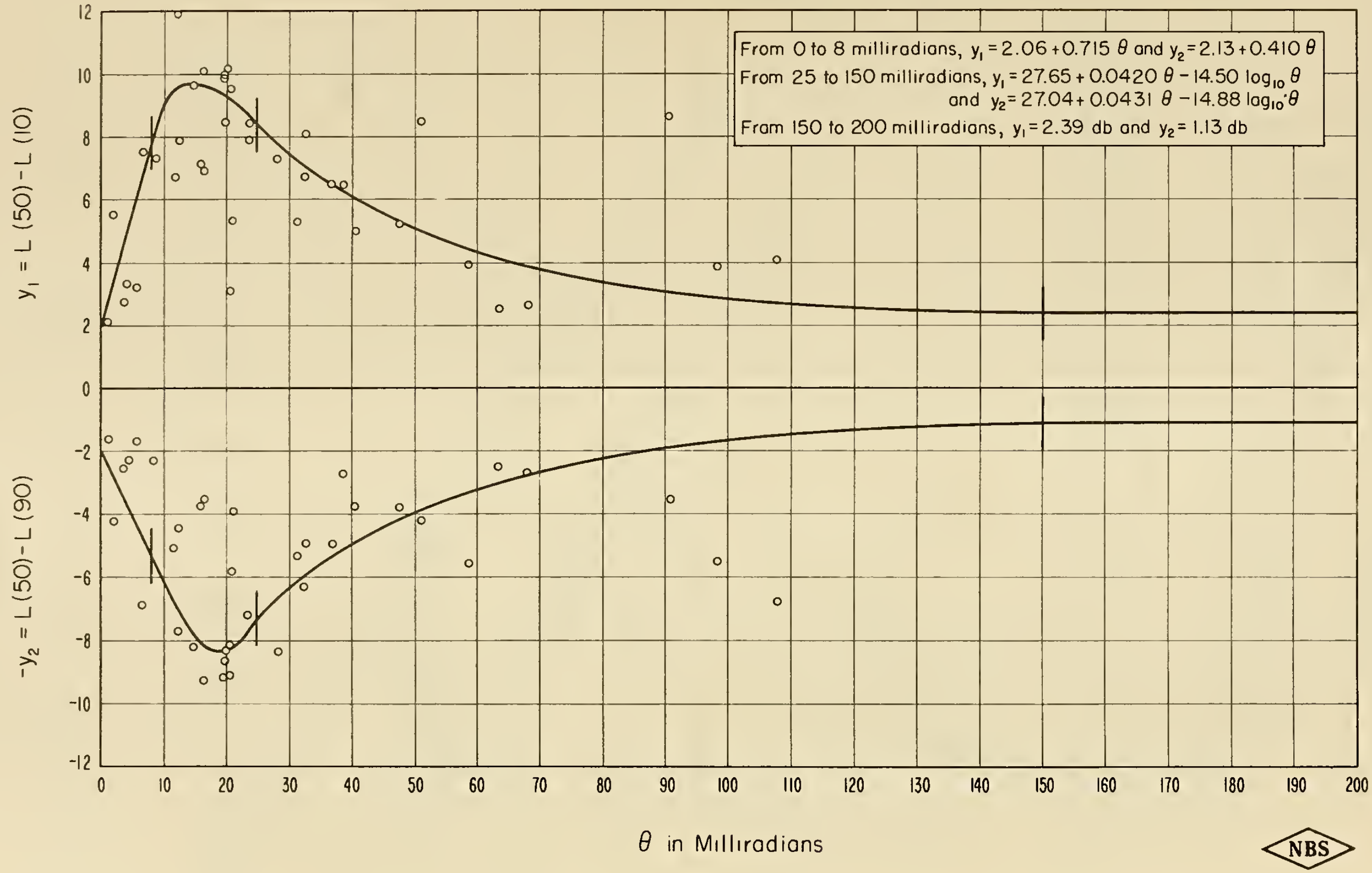


Figure 7

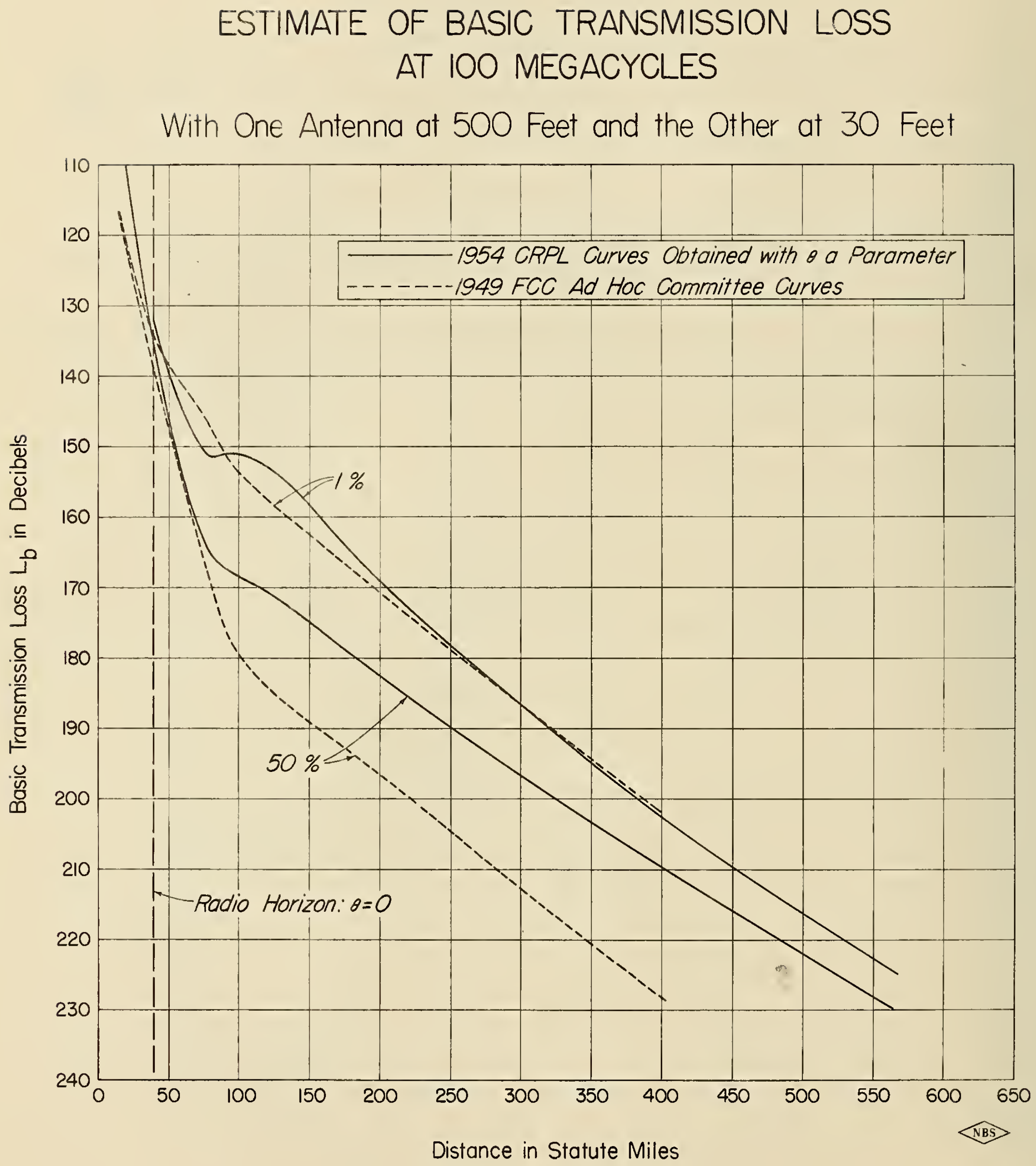

ESTIMATE OF BASIC TRANSMISSION LOSS
AT 100 MEGACYCLES
With One Antenna at 500 Feet and the Other at 30 Feet
1954 CRPL Curves Obtained with θ a Parameter
1949 FCC Ad Hoc Committee Curves
1 %
50 %
Radio Horizon: θ=0
Basic Transmission Loss L_b in Decibels
Distance in Statute Miles
110
120
130
140
150
160
170
180
190
200
210
220
230
240
0
50
100
150
200
250
300
350
400
450
500
550
600
650
NBS

Figure 8

MEDIAN BASIC TRANSMISSION LOSS L_{bm} VERSUS ANGULAR DISTANCE

One Antenna Height Fixed at Thirty Feet
Other Antenna Height as Indicated

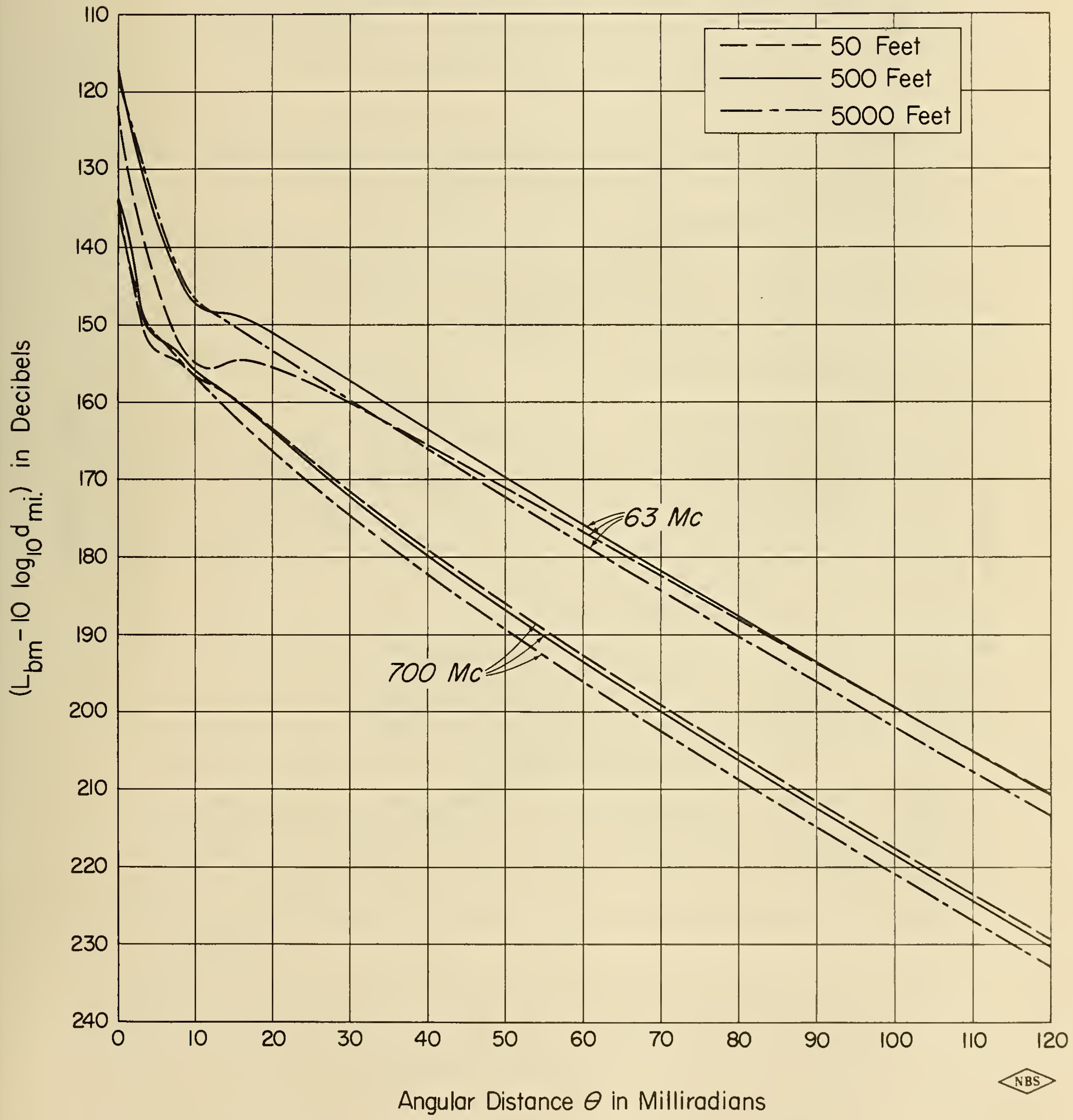


Figure 9

MEDIAN BASIC TRANSMISSION LOSS L_{bm} VERSUS DISTANCE

One Antenna Height Fixed at Thirty Feet
Other Antenna Height as Indicated

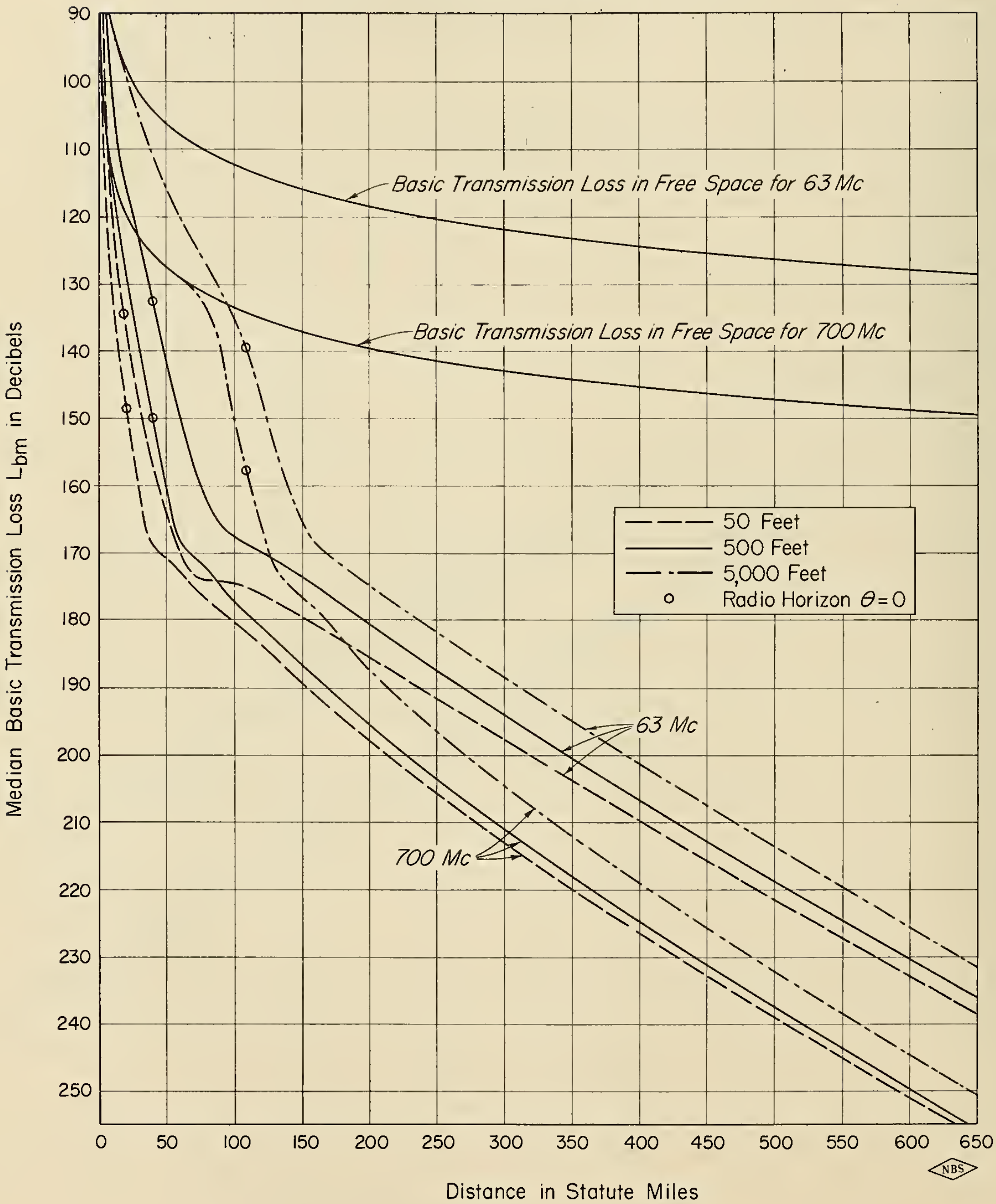


Figure 10

CORRECTION TO THE THEORETICAL MEDIAN SMOOTH EARTH BASIC TRANSMISSION LOSS TO BE EXPECTED BEYOND LINE OF SIGHT OVER IRREGULAR TERRAIN

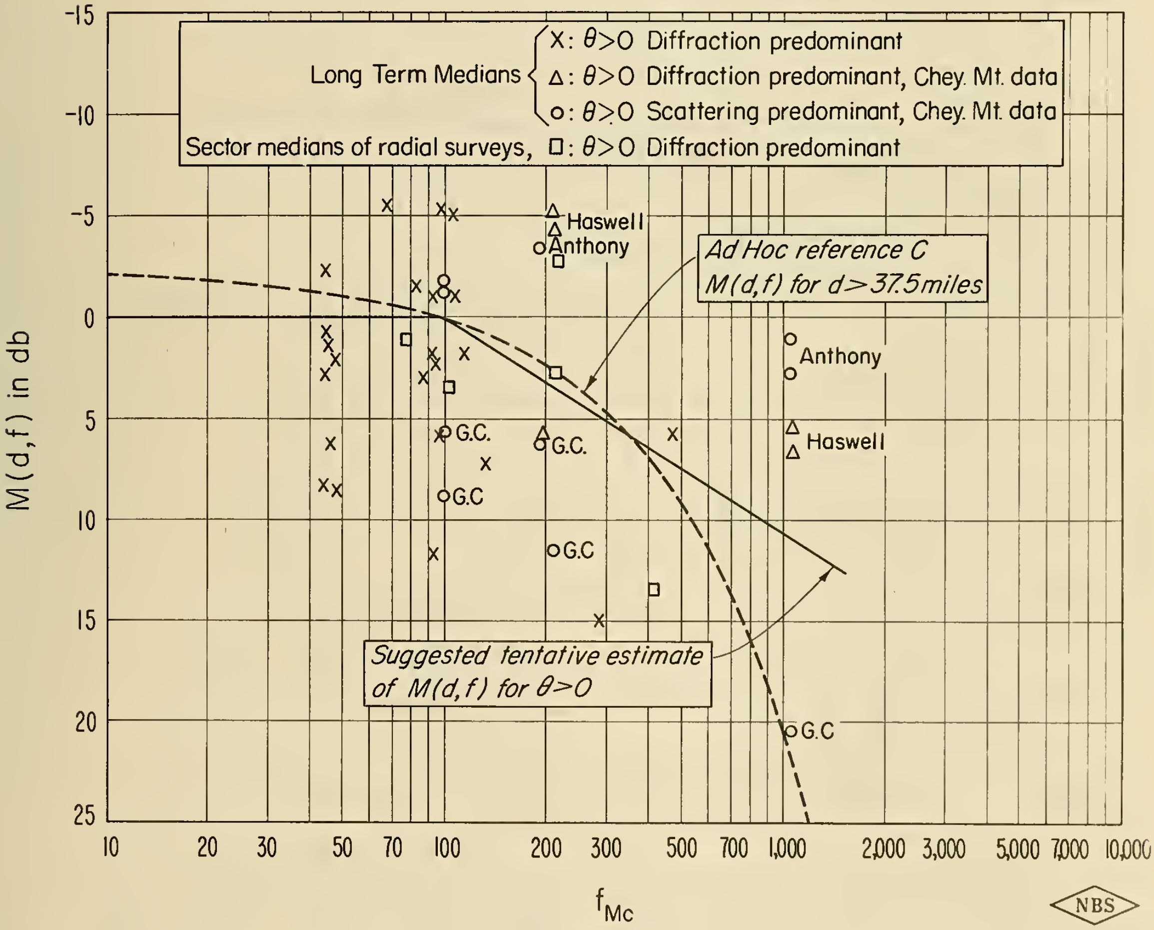


Figure 11

CORRECTION TO THE THEORETICAL SMOOTH EARTH BASIC TRANSMISSION LOSS OVER IRREGULAR TERRAIN FOR 63 AND 700 MC

One Antenna at 30 Feet, Other Antenna Height as Indicated

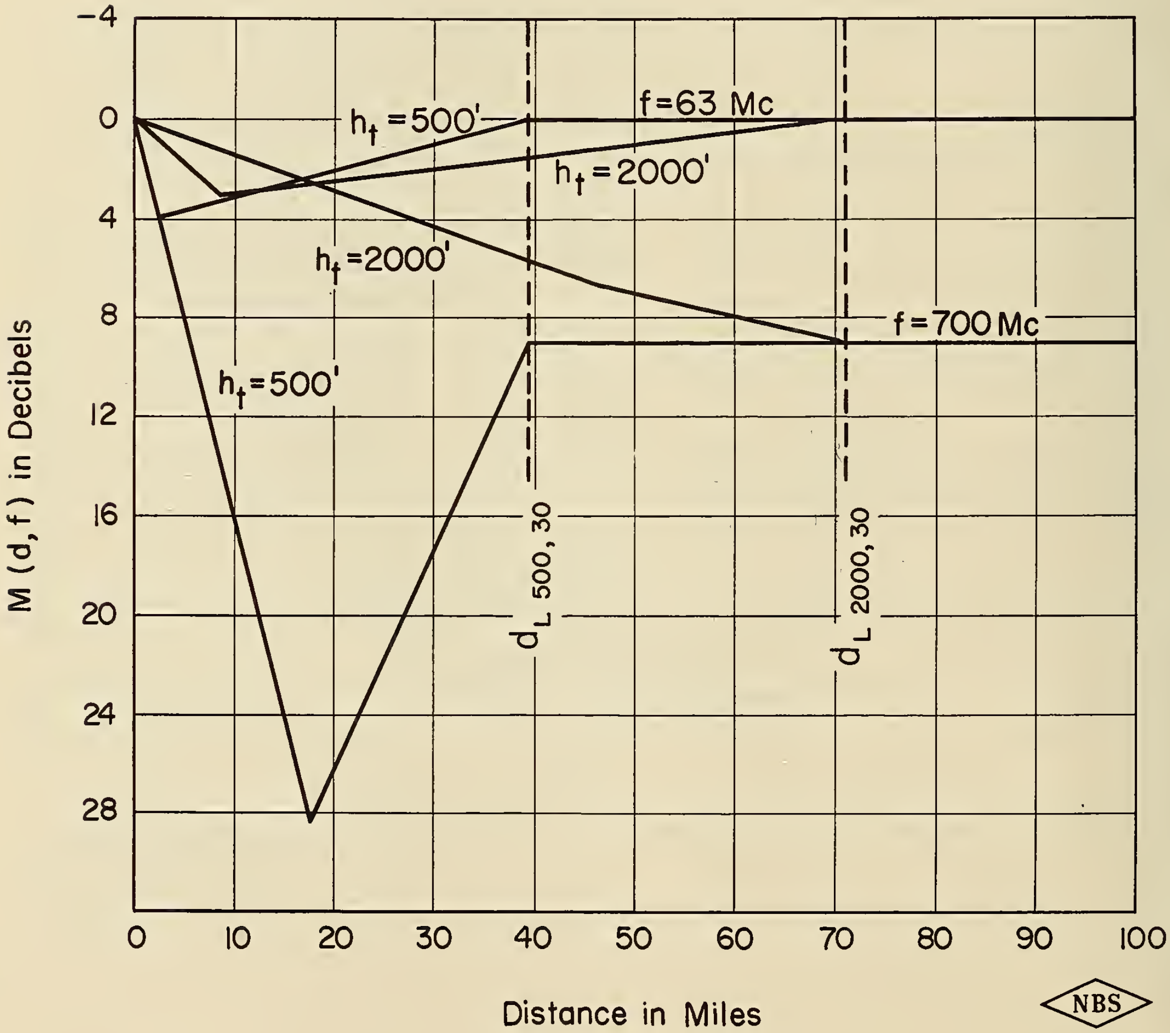


Figure 12

RELATIVE NUMBER OF LOCATIONS RECEIVING ACCEPTABLE SERVICE IN THE PRESENCE OF INTERFERENCE FROM A SINGLE OFFSET CO-CHANNEL STATION

Acceptable Service Exists Wherever the Desired Signal Overcomes Noise and Interference at Least 90% of the Time

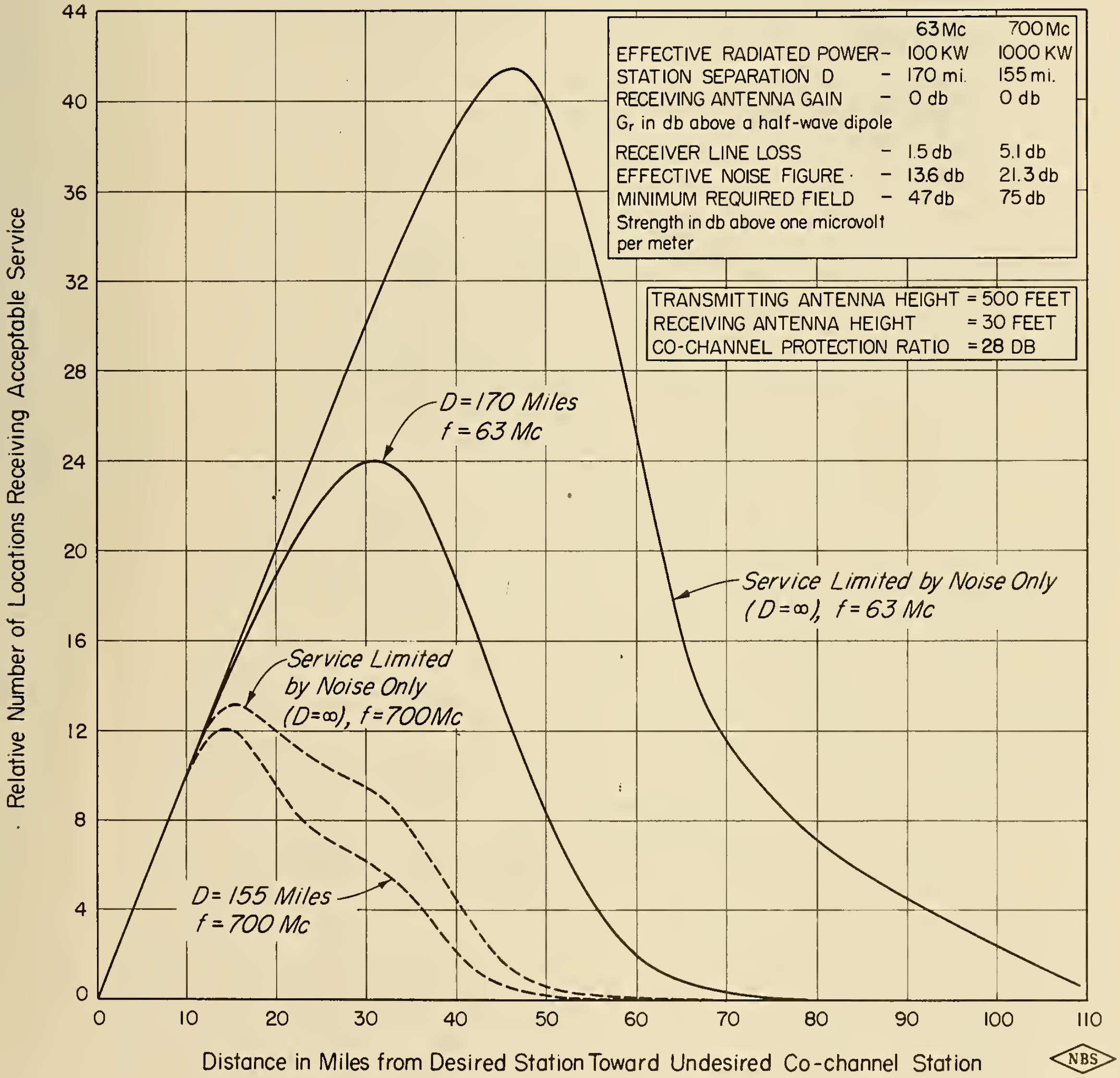


Figure 13

RELATIVE NUMBER OF LOCATIONS RECEIVING ACCEPTABLE SERVICE IN THE PRESENCE OF INTERFERENCE FROM A SINGLE OFFSET CO-CHANNEL STATION

Acceptable Service Exists Wherever the Desired Signal Overcomes Noise and Interference at Least 90% of the Time

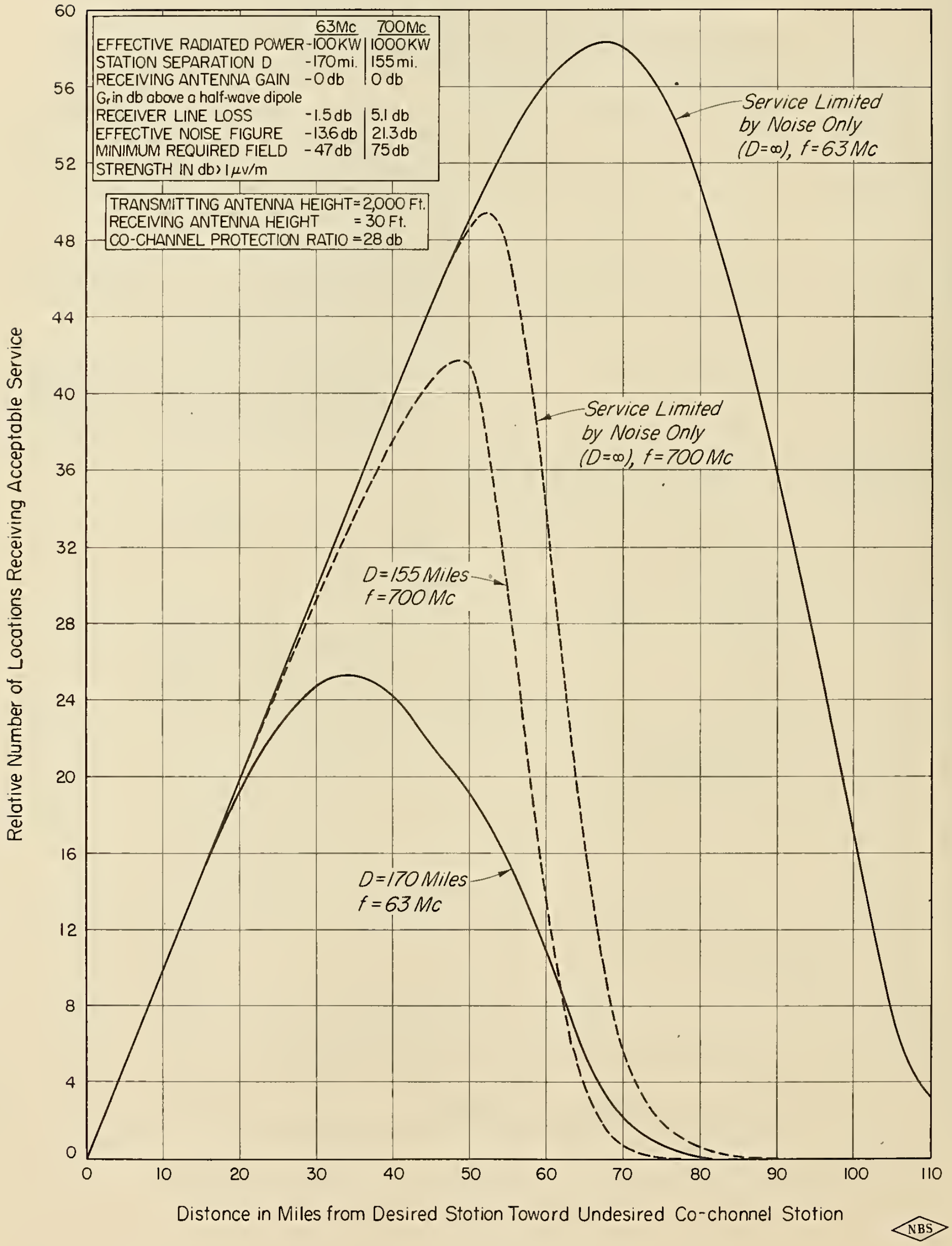


Figure 14

Supplement XIX

WRIGHT FIELD LETTERS

Supplement XIX

WRIGHT FIELD LETTERS

No. 1 November 6, 1947 14.4

Colonel S. A. Mundell
Air Materiel Command
Electronic Subdivision
Engineering Division
Wright Field
Dayton, Ohio

Attention: TSELC5C2

Subject: VHF-UHF Range Tests

Dear Colonel Mundell:

Work is progressing on a theoretical propagation study concerning the above subject on the basis of the information supplied in your letter of September 5, 1947.

Assuming that 6 watts are actually radiated from the transmitting antenna and that the antenna actually has a directivity characteristic equivalent to that of a half wave dipole in free space, the free space field intensity in the direction of maximum radiation from the antenna will be 10,600 microvolts per meter at one mile.

Assuming that the receiving antenna actually has an absorbing area equivalent to that of a half wave dipole and that all of the available absorbed power is actually delivered to the receiver input, it follows that a field intensity of 24.9 microvolts per meter is required at 328 Mc to deliver a voltage of 3 microvolts across the receiver input impedance which is assumed for these calculations to be 50 ohms. (This value of impedance was not included in the September 5 letter and we should be informed if the assumed value of 50 ohms is correct).

From the above, the calculated free space maximum range is (10,600/24.9 = 428 miles; the observed air-to-air range of 200 miles at 17,000 feet implies, if we neglect the presumably negligible effects of ground reflection, that the assumption in the above paragraphs are optimistic by only 6.6 decibels.

In order to obtain more precise results, the following information would be useful:

(a) The measured radiation in the horizontal plane (free space field intensity at one mile) from the aircraft antenna. This could be measured by comparison with the radiation from a standard field generator.

(b) The measured field intensity required to deliver a voltage of 3 microvolts across the receiver input impedance. This could also be measured by means of a standard field generator.

(c) The transmission line lengths, impedance, and loss characteristics per unit length; also the probable mismatch losses for transmission and reception.

The calculations of the expected air-to-ground performance involving the ground reflection lobes is not yet complete but the results so far appear to bear out the conclusions tentatively reached at the meeting here at CRPL. However, because of the rough terrain along the propagation path quantitative agreement cannot be expected. For this reason it is considered to be of great importance to plan air-to-ground tests of this equipment at some location where the terrain within 30 miles of the ground station antenna is more nearly level than that near Wright Field.

Expected air-to-ground performance over a smooth earth is now being calculated for several ground antenna heights and for both 328.2 and 139.14 Mc; these data will be furnished as soon as completed.

Very truly yours,

/s/

Kenneth A. Norton, Chief
Frequency Utilization Research Section
Central Radio Propagation Laboratory

No. 2 January 29, 1948 14.4

Colonel S.A. Mundell
Air Materiel Command
Electronic Subdivision
Engineering Division
Wright Field, Dayton, Ohio

Attention: TSELC5C2

Subject: VHF-UHF Range Tests

Dear Colonel Mundell:

This letter is written with the object of informing you of our progress to date on the problem of analyzing the propagation characteristics of VHF and of UHF frequencies for use in air-to-air and air-to-ground communication. This project was started as a result of a conference held at CRPL on August 14, 1947 discussing the significance of the comparative measurements made at Wright Field of the ranges of similar VHF and UHF equipment. The conclusions reached at that conference have been substantially verified by our subsequent calculations. Thus we have reached the following conclusions:

(1) The free-space-range for non-directive antennas will decrease in direct proportion to the frequency provided the receiver sensitivity and transmitter power are the same for the various frequencies. This decrease in range is due to a decrease with increasing frequency in the absorbing area of the non-directional receiving antenna. Since it is undoubtedly impracticable to use much, if any, directivity on the aircraft antennas it follows that the service range for the UHF equipment can be made equal to that on the VHF band only by using additional transmitter power in direct proportion to the square of the frequency. Thus a 6 watt transmitter on 120 Mc/s will have the same free-space-maximum range as a 54 watt transmitter on 360 Mc/s. This conclusion is modified to some extent by the effect of the ground as discussed below.

(2) The reliable air-to-air maximum range will be very nearly equal to the free-space-maximum range. The waves reflected from the ground will tend to cause the received field to fade (as the aircraft change their distance or direction from each other)but the signals received in an airplane from another airplane well above the line-of-sight would be expected to be usable for more than 90% of the time at a distance corresponding to half of the distance to the free-space-maximum range and for more than 60% of the time at the free-space-maximum range. Curves showing the air-to-air ranges to be expected for various percentages of the time will be supplied in a later letter. In the meantime reference may be made to our letter of November 6 in which it was stated that the calculated free-space-maximum range on 328 Mc/s is 428 miles; this calculated value was based on the assumption of no losses throughout the system. If we allow 6 db for transmission line or mismatch losses, the expected free-space-maximum range will be only 214 miles. Thus the calculations indicate that satisfactory air-to-air signals (greater than 3 microvolts) will be available across the receiver terminals for more than 90% of the time at a distance of 107 miles and for more than 60% of the time at a distance of 214 miles. In your letter of September 5, 1947 the measured maximum reliable range on 328 Mc/s for aircraft at 17,000 and 30,000 feet was given as 200 miles; this value is considered to be in good agreement with the theory especially when it is considered that the 6 db assumed loss may be somewhat too large. The measured decrease with increasing frequency in the reliable air-to-air range from 200 miles at 328 Mc/s to only 150 miles at 400 Mc/s is slightly more than inversely proportional to the frequency; this slight additional decrease in range, over and above the inverse frequency variation expected because of receiving antenna absorbing area changes, also is in accord with the theory because of the slightly larger receiver noise figures and system losses to be expected at the higher frequencies.

(3) The ground-to-air (or air-to-ground) problem is more complex and the situation in this case can best be understood by carefully studying the four figures enclosed with this letter. Figures 1 and 2 show the expected ground-to-air range over a smooth spherical earth with a transmitting and receiving antenna pattern similar to that of a half-wave vertical dipole. Figure 1 shows the expected coverage of a 6 watt transmitter operating on 138 Mc/s. For example, an airplane flying at an altitude of 30, 000 feet will receive signals in excess of 12 microvolts out to a range of about 80 miles at which distance the received signals may be expected to drop to 8 or 10 microvolts. At greater distances the signals again increase and remain above 12 microvolts out to a distance of 12 miles. Between 120 and 150 miles the received signals will drop down to 2 or 3 microvolts but again increasing with increasing distance out to 200 miles at which a received signal of 12 microvolts is expected. Beyond 200 miles the signals again decr ase, finally dropping below 3 microvolts at 240 miles, which is the expected maximum range for an aircraft flying at 30, 000 feet over a smooth earth. It should be emphasized that the coverage contours shown on this figure as well as on igures 2 and 3 are for antennas which have transmission and reception characteristics symmetrical about the horizontal plans. The vertical pattern of both the ground and aircraft antennas submitted with your letter dated January 13, 1948 indicate substantial differences in radiation for similar angles above and below the horizontal. Thus the direct wave and ground reflected wave radiation will be different and this will have the effect of decreasing the coverage at angles near those corresponding to the maxima of the lobes and will increase the coverage at angles near those for the lobe minima. Reference to the antenna pattern submitted will indicate that this unsymmetry in the vertical plane will not be a large factor in the coverage except for the region more than about five degrees above the horizon.

Figure 2 shows the expected coverage of a 328 Mc/s system with the same transmitter power and antenna height. The difference between the coverage on 328 Mc/s and 138 Mc/s can best be appreciated by considering the lowest lobes on figures 1 and 2 within which a signal in excess of 12 microvolts may be expected. On figure 1 this lowest lobe has a maximum extending to 235 miles while the corresponding maximum on figure 2 is only 100 miles. It is quite clear from figures 1 and 2 that the coverage on the higher frequency is much more spotty and generally less dependable. In one respect the theory does indicate that the higher frequency system is almost as good as the lower frequency system and this is with respect to the absolute maximum range over a smooth earth, i.e., the distance, at the same height, to the point on the bottom of the lowest lobe at which a signal of 3 microvolts is expected. On 138 Mc/s this distance is 240 miles for an aircraft at 30,000 feet and is 233 miles on 328 Mc/s.

Figures 1 and 2 are for a smooth earth and standard atmosphere. Reference to figure 4 shows that the terrain involved in the Wright Field tests was far from being sufficiently smooth to expect the coverage diagrams of figures 1 and 2 to be applicable. Shown on figure 4 are the distances (for the two frequencies) out to the centers of the Fresnel zones within which the ground reflection can be considered to take place for aircraft flying at some point near the maximum of the lowest lobe when the propagation is over a smooth spherical surface. These effective reflection zones begin several miles short of the indicated zone centers and extend several miles beyond these centers. According to the paper "The Maximum Range of a Radar Set", Proc. IRE, January 1947, page 24, the allowable deviations in terrain height, Δh, must be less than one-fourth of the transmitter height over the entire Fresnel zone if the first lobe of coverage is to be well developed. We see by figure 4 that the actual variations within this zone are much greater than the permissible 30 feet and we conclude that the actual propagation will deviate significantly from the predicted smooth earth values. Irregularities in terrain will tend to reduce the ranges to be expected at angles near the maximum of the lobe and to increase the ranges to be expected at angles near the lobe minima. Theoretical curves for the ranges to be expected in very rough terrain are now being prepared and will be given in a later letter.

The observed air-to-ground range for an aircraft at 30,000 feet was stated to be 220 miles and this is only slightly less than the 240 miles expected for a smooth earth as shown on figure 1. This small difference between measurement and theory might easily be caused by irregularities in terrain such as those on figure 4; it should be noted that the irregularities in terrain would be expected to affect the lower frequency somewhat less because the Fresnel zone of reflection occurs nearer to the transmitting antenna and covers a smaller area. On 328 Mc/s the observed reliable air-to-ground range for an aircraft at 30,000 feet was stated to be only 90 miles with spotty reception beyond that distance. Reference to figure 3 indicates either that irregularities in terrain must have had serious effects upon the four lowest lobes or that the system loss for this particular flight test was unusually high. Calculations indicate that the Fresnel zone for propagation to the middle of the fourth lobe extends from 0.23 to 0.99 miles from the base of the antenna and reference to figure 4 indicates that the terrain is very flat over this range of distances; permissible height deviations are, however, only about 3 feet (actually one thirty-sixth of the transmitting antenna height) for this fourth lobe Fresnel zone and thus place a severe requirement on the site required to realize the conditions postulated in the theory. Nevertheless, it does seem surprising that the effective air-to-ground range on 328 Mc/s was not greater than 90 miles; further measurements to confirm this unexpectedly low range are suggested.

(4) One practicable method of improving the air-to-ground range on 328 Mc/s is to use a ground station antenna with directivity in the vertical plane. For example, the use of four vertically-stacked half-wave dipoles will be non-directional in the horizontal plane but will tend to concentrate the radiation near the horizon in such a way that the power gain for either transmission or reception will be 2.62 times the value for a single half-wave dipole. The air-to-ground coverage for such an antenna is shown on figure 3 and we see that the coverage of such a system is considerably improved. The long dashed curve on this diagram is the envelope of the 12

microvolt lobe maxima and we see that the use of this vertically directive antenna produces a gap in coverage at an angle of 30° above the horizon. This gap extends for several miles at the higher heights and might be considered undesirable; however, such a gap is inevitable with vertically directive antennas and represents the price which must be paid for the added range at angles nearer to the horizon.

(5) Coverage over a smooth earth almost identical to that shown on figure 1 for 138 Mc/s may be obtained on 328 Mc/s by decreasing the transmitting antenna height in proportion to the increase in frequency, i.e., to a height $h = 115 \times (138/328) = 48$ feet and simultaneously increasing the effective transmitter power in proportion to the square of the frequency, i.e., to a power $= 6 \times (328/138)^2 = 34$ watts. Work is now in progress on the problem of computing the expected coverage on 328 Mc/s for this case but it is known in advance that it will be closely similar to that shown on figure 1 for 138 Mc/s.

It is considered most desirable that further tests be conducted on the 328 and 138 Mc/s transmission from a site which is sufficiently smooth to make possible a check of the calculated smooth earth ranges and from another site sufficiently rough so that random ground reflections can be considered in the calculations. The proper interpretation of such tests can be made only from continuous records of the received field intensity. Thus a requirement for such tests is the availability of a transmitter which may be operated continuously for several hours. Ideally this should be an airborne transmitter, but, if only a ground transmitter is available the field intensity recording might be done in the airplane.

The additional calculations mentioned above will be supplied as soon as they become available. In the meantime it will be appreciated if you will keep us advised of the results of any further measurements made of either the ranges or of the transmitter, receiver or antenna characteristics.

Very truly yours,

/s/

Kenneth A. Norton, Chief
Frequency Utilization Research Section
Central Radio Propagation Laboratory

No. 3 April 22, 1948 14.4

Colonel S.A. Mundell
Air Materiel Command
Electronic Subdivision
Engineering Division
Wright Field
Dayton, Ohio

Attention: TSELC5C2

Subject: VHF-UHF Range Tests

Dear Colonel Mundell:

This letter is written with the object of informing you of further progress in the analysis of the air-to-air propagation characteristics of the UHF and VHF frequencies used in air-to-air and air-to-ground communications. Reference is made to a letter from Mr. K.A. Norton of this office dated January 29, 1948, which contained the primary results of the air-to-ground portion of the analysis and a preliminary analysis of the relative air-to-air performance in the VHF and UHF bands.

The results of further study of the air-to-air portion of the problem are presented in the attached figures 5 and 6 wherein the calculated performance on both 138 Mc/s and 328 Mc/s for two aircraft flying at the same altitude are shown. These figures show the regions within which (a) well defined lobe structure would be expected, (b) the transition regions between well defined lobe structure and Rayleigh distributed ground reflected waves, and (c) the region where the space-wave is made up of a direct wave and a Rayleigh distributed ground reflected wave. These regions are calculated for irregular terrain wherein height deviations from smooth earth conditions are as great as 100 feet particularly within the first Fresnel zone. For larger irregularities of terrain and on higher frequencies the regions of well defined lobe structures and the transition regions would be a smaller fraction of the total coverage area.

The solid line range reliability curves shown in the upper region give the percentage of the time that three microvolts across the receiver input terminals would be expected considering the received field to be made up of a direct wave and a Rayleigh distributed ground reflected wave. These curves are shown dashed in the transition region and apply only if the terrain is sufficiently irregular to produce Rayleigh distributed ground reflected waves in this intermediate region. The radio line-of-sight, shown as a dashed line on the figures, is the height at each end of the transmission path of a plane tangent at the mid-point of the path to the spherical earth with a radius 4/3 of the actual radius of the earth to allow for average air refraction.

The method ordinarily employed for calculations of received UHF field intensity well within the line-of-sight involves the vector sum of a direct wave and a ground reflected wave which is assumed to be reflected from a smooth spherical earth. Calculations using this method result in well defined "lobe structures" as has been illustrated in figures 1, 2, and 3 of Mr. Norton's previous letter, and which have been found to exist in VHF and UHF air-to-ground propagation. However, when the limitations given in the paper "The Maximum Range of a Radar Set" are applied in calculations for very high antennas on each end of the path (communication between two high flying aircraft) to determine the minimum deviations in the height of the terrain within the principal region from which the signal from the ground is reflected, it is found that unless only small variations in the height of terrain exist, the lobes will not be well defined in a large portion of the coverage region. The limiting irregularities of height for well defined lobes vary with altitude, distance and frequency.

A new theoretical approach to the problem of calculating range reliability of air-to-air communication was employed in arriving at the reliability contours shown in figures 5 and 6. In this approach it is assumed that the terrain involved is sufficiently irregular so that the received space-wave field is made up of a conventional direct wave and a random phased ground reflected wave, the intensity of which is distributed in accordance with the Rayleigh distribution. The Rayleigh distribution is that which would be expected when a large number of signal components arrive at the receiving location in random phase as might result at UHF and VHF from reflections from irregular terrain consisting of hills, valleys, trees, buildings, and the like. The combination of the random phased Rayleigh distributed ground reflected wave with a direct wave has resulted in the statistical spatial representation of communication reliability shown for the two frequency bands in the two upper regions on figures 5 and 6. (Note: for stationary objects at the altitudes and distances indicated, instead of percentage of time, the charts would read the probability that the field intensity would be sufficient to produce 3 microvolts across the receiver input terminals.)

When the terrain is sufficiently irregular to produce ground reflected path length differences deviating from the smooth earth conditions by as much as $\lambda/8$, the lobe structure begins to break down. When this irregularity is sufficient to produce ground reflected path length deviations of one wavelength from smooth earth conditions and the irregularities are at random, the phase of the ground reflected portion of the space-wave is assumed to be random and its intensity Rayleigh distributed. These two conditions are shown on the figures for deviations in terrain height of 100 feet from smooth earth conditions as the lower and upper boundaries respectively of the transition region. Deviations in terrain height are particularly important in the first Fresnel zone, the size of which depends upon the antenna heights, distance, and frequency. Some idea of its magnitude can be gained by taking an arbitrary case of two aircraft at 10,000 feet 100 miles apart. Here it can be shown using the equations from "The Maximum Range of a Radar Set," that the dimensions of the first Fresnel zone ellipse are 7.2 miles long and 0.24 miles wide at 328 Mc/s and 11.3 miles long and 0.37 miles wide at 138 Mc/s. Referring to figure 4 of Mr. Norton's letter of January 29, 1948, a perfunctory examination of the terrain to the west of Wright Field, Ohio, would indicate that 100 foot variations in height within the first Fresnel zone is a reasonable figure for the illustrated terrain contours west of Wright Field.

The conclusions reached with regard to the relative merits of the two frequencies for plane to plane communications based on the above new theoretical approach to the VHF-UHF air-to-air problem are given in paragraph (2) of the January 29 letter. Figures 5 and 6 just give the detailed results of the calculations mentioned in that letter.

It should be emphasized that the above mentioned new theorecical approach upon which figures 5 and 6 are based is tentative and to our knowledge only meager experimental data exists that may be analyzed to substantiate it. At a meeting held April 6, 1948 between members of the Army Air Forces, Navy Department and the Central Radio Propagation Laboratory, results of recent air-to-air VHF-UHF tests made for the Navy by Collins Radio Corporation were made available to the CRPL for analysis. A preliminary analysis of the over-land air-to-air recordings indicates that the data are in general agreement with the irregular terrain theory. Further study of these data is in progress and other results will be furnished as obtained particularly as regards the application of similar statistical approach to air-to-air VHF-UHF propagation over smooth terrain. In view of the sparceness of experimental data on air-to-air VHF-UHF propagation, it may be desirable for your organization to instigate an experimental study designed to test this new approach to the problem in cooperation with the Central Radio Propagation Laboratory. It is not feasible for CRPL alone to carry out experiments of this type since required equipment and aircraft are at present not available.

In paragraph (5) of the January letter, it was mentioned that air-to-ground coverage over a smooth earth on 328 Mc/s almost identical to that shown on figure 1 for 138 Mc/s could be obtained by decreasing the transmitting antenna height in proportion to the increase in frequency (from 115 to 48 feet) and simultaneously increase the effective transmitting power in proportion to the square of the frequency (from 6 to 34 watts). Figure 7 has been computed for these conditions (ground antenna height above average terrain = 48 feet; the effective transmitting power 13 x 4.29/1.64 = 34 watts) and it may be seen that this coverage pattern for 328 Mc/s is practically identical to that shown in figure 1 for 138 Mc/s as was expected. In this computation, the ground antenna is assumed to be a four element colinear array with a power gain of 4.29 over an isotropic antenna; with its use the free space maximum range for 328 Mc/s was made equal to that of 138 Mc/s by increasing the power by a factor of 2.16 as compared with a factor of 5.65 necessary if half-wave dipoles had been assumed for both frequencies. A null at 30° above the horizon is the price paid for using a colinear array instead of a higher power transmitter.

It will be appreciated if you will keep us advised of the results of any further measurements made of either the ranges of the transmitter, receiver or antenna characteristics. It is considered most desirable that further well planned measurements be made as previously suggested. If you so desire, arrangements may be made to have a member of CRPL familiar with the theoretical propagation aspects of the air-to-air/air-to-ground communications problem visit your laboratory for further discussion and assist with future measurements and tests.

Very truly yours,

/s/

Jack W. Herbstreit
Frequency Utilization Research Section
Central Radio Propagation Laboratory

138 Mc RADIATION PATTERN FOR GROUND TO AIR COMMUNICATION OVER A SMOOTH SPHERICAL EARTH

TRANSMITTING ANTENNA GAIN: 1.64 (relative to an isotropic);
POWER: 6 WATTS; HEIGHT: 115 FEET; VERTICAL POLARIZATION

RECEIVING ANTENNA GAIN: 1.64

ASSUMED COMMUNICATION SYSTEM LOSS: 6 db

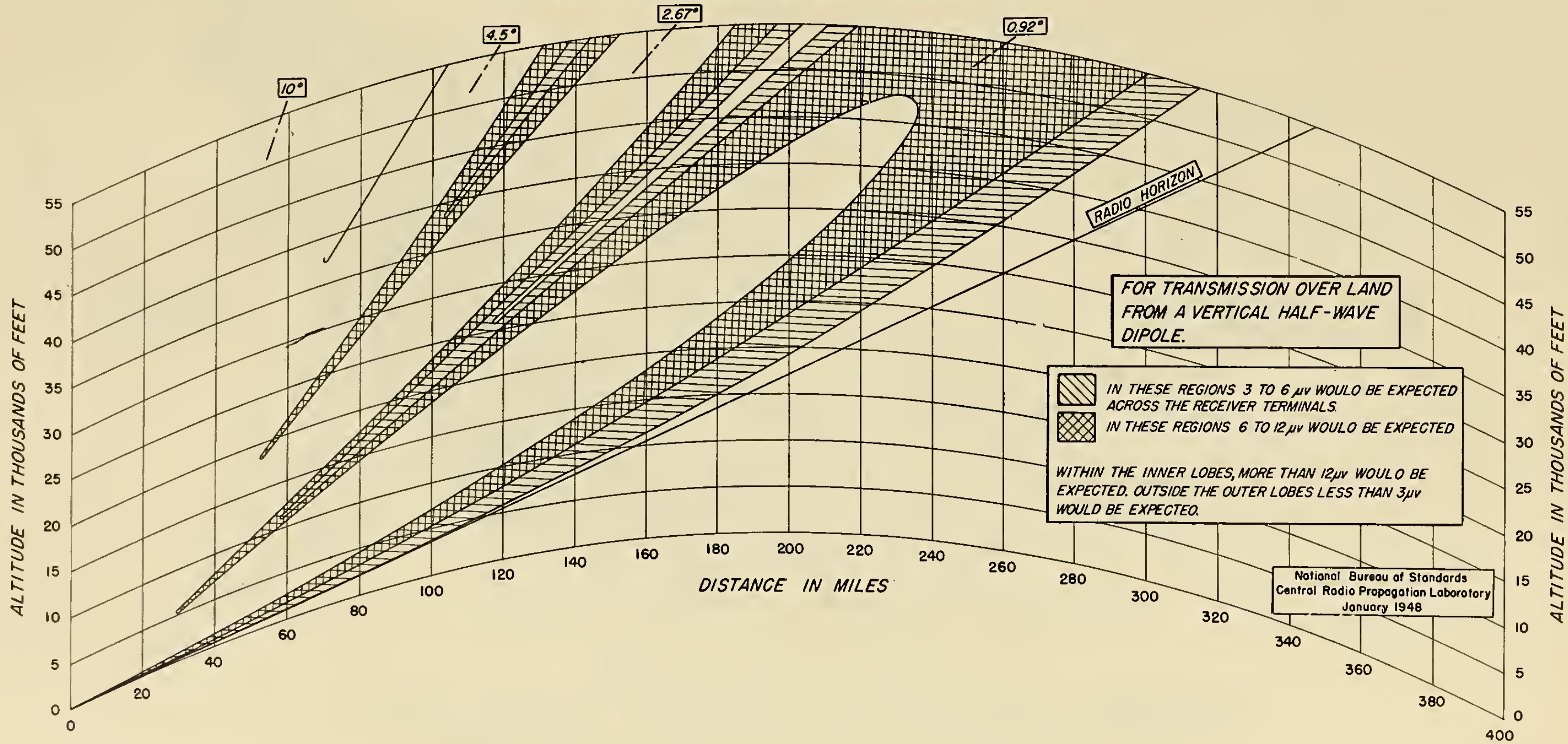


FIGURE 1

NBS

328 Mc RADIATION PATTERN FOR GROUND TO AIR COMMUNICATION OVER A SMOOTH SPHERICAL EARTH

TRANSMITTING ANTENNA GAIN: 1.64 (relative to an isotropic);
POWER; 6 WATTS; HEIGHT: 115 FEET; VERTICAL POLARIZATION

RECEIVING ANTENNA GAIN: 1.64

ASSUMED COMMUNICATION SYSTEM LOSS: 6 db

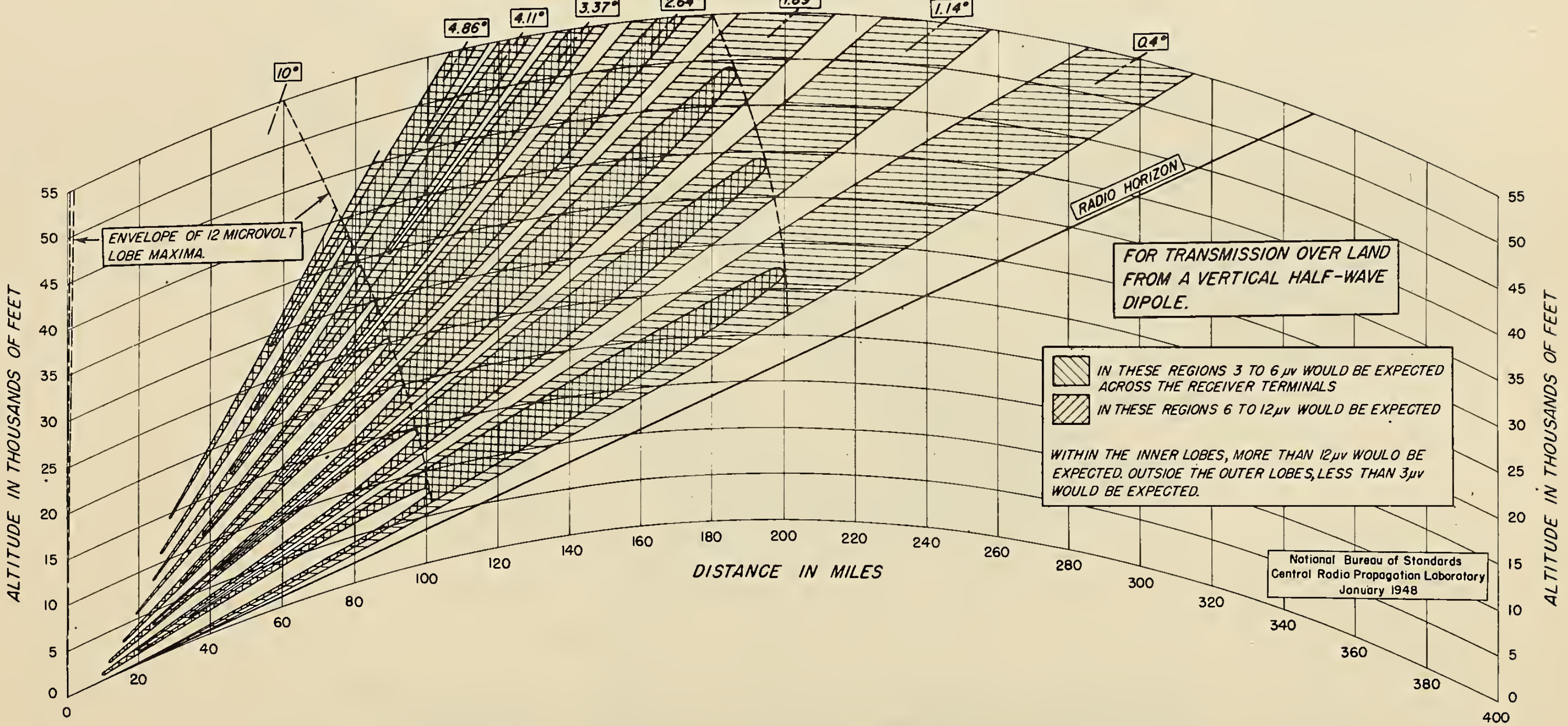


FIGURE 2

NBS

328 Mc RADIATION PATTERN FOR GROUND TO AIR COMMUNICATION OVER A SMOOTH SPHERICAL EARTH

TRANSMITTING ANTENNA GAIN: 4.29 (relative to an isotropic);
POWER: 6 WATTS; HEIGHT: 115 FEET; VERTICAL POLARIZATION

RECEIVING ANTENNA GAIN: 1.64

ASSUMED COMMUNICATION SYSTEM LOSS: 6 db

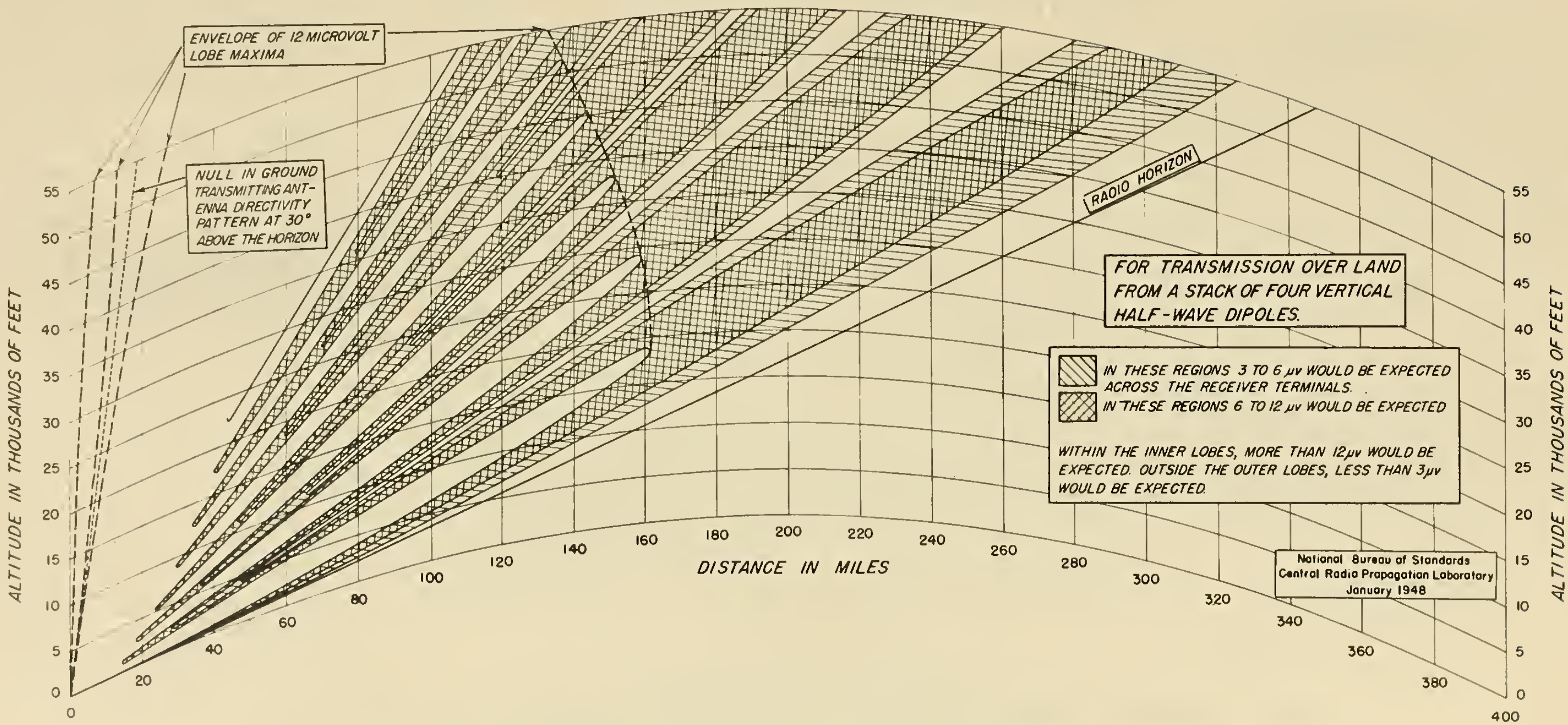
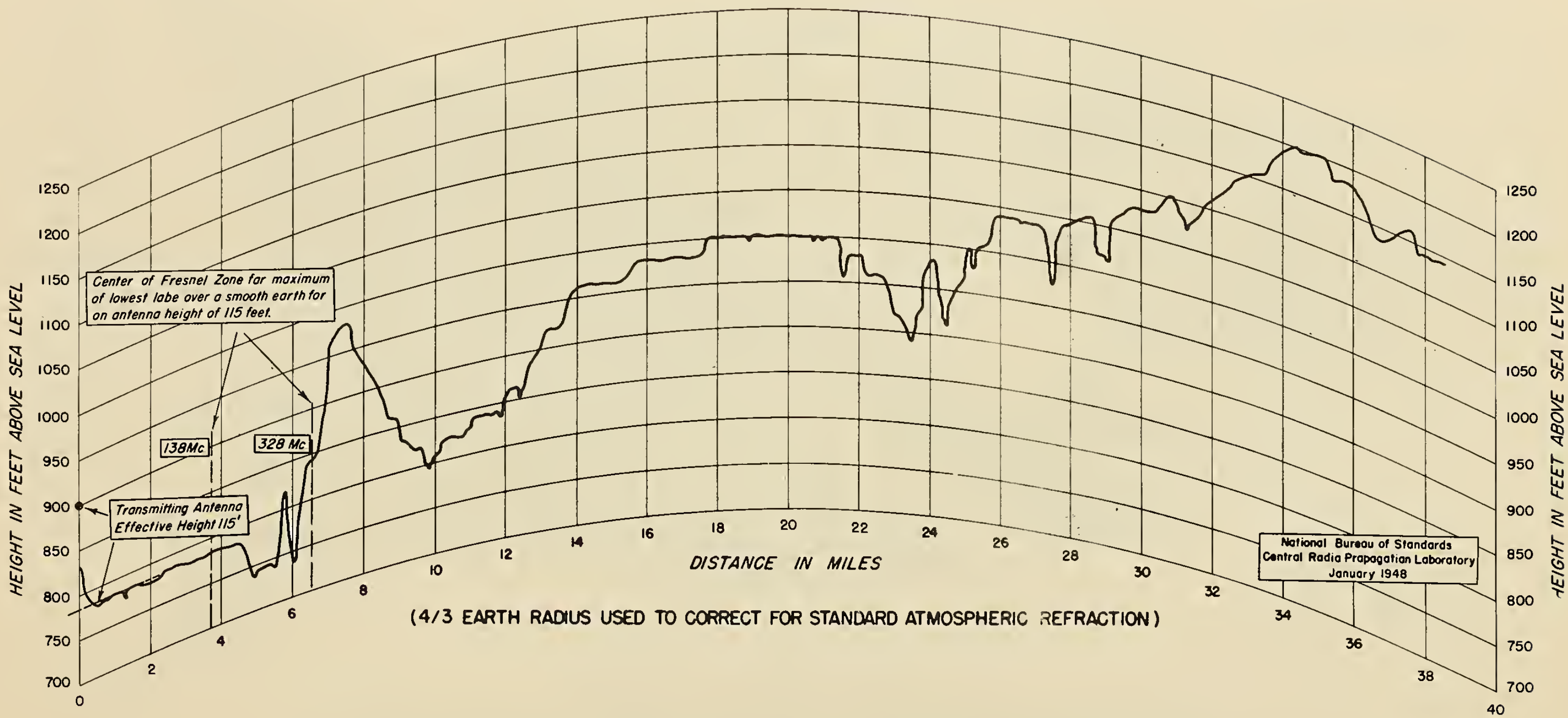


FIGURE 3

NBS

TERRAIN INVOLVED IN GROUND TO AIR COMMUNICATIONS TESTS

PROFILE SHOWS ELEVATIONS IN FEET ABOVE SEA LEVEL OF FIRST FORTY MILES FROM WRIGHT FIELD, OHIO, PENTHOUSE IN THE DIRECTION OF GREENFIELD, OHIO



NBS

FIGURE 4

RECEIVED FIELD DISTRIBUTION FOR AIR TO AIR COMMUNICATION
ON 138 Mc/s OVER IRREGULAR TERRAIN FOR TWO AIRCRAFT
FLYING AT THE SAME ALTITUDE

TRANSMITTING ANTENNA GAIN: 1.64 (relative to an isotropic);
POWER: 6 WATTS; VERTICAL POLARIZATION

RECEIVING ANTENNA GAIN: 1.64

ASSUMED COMMUNICATION SYSTEM LOSS: 6 db

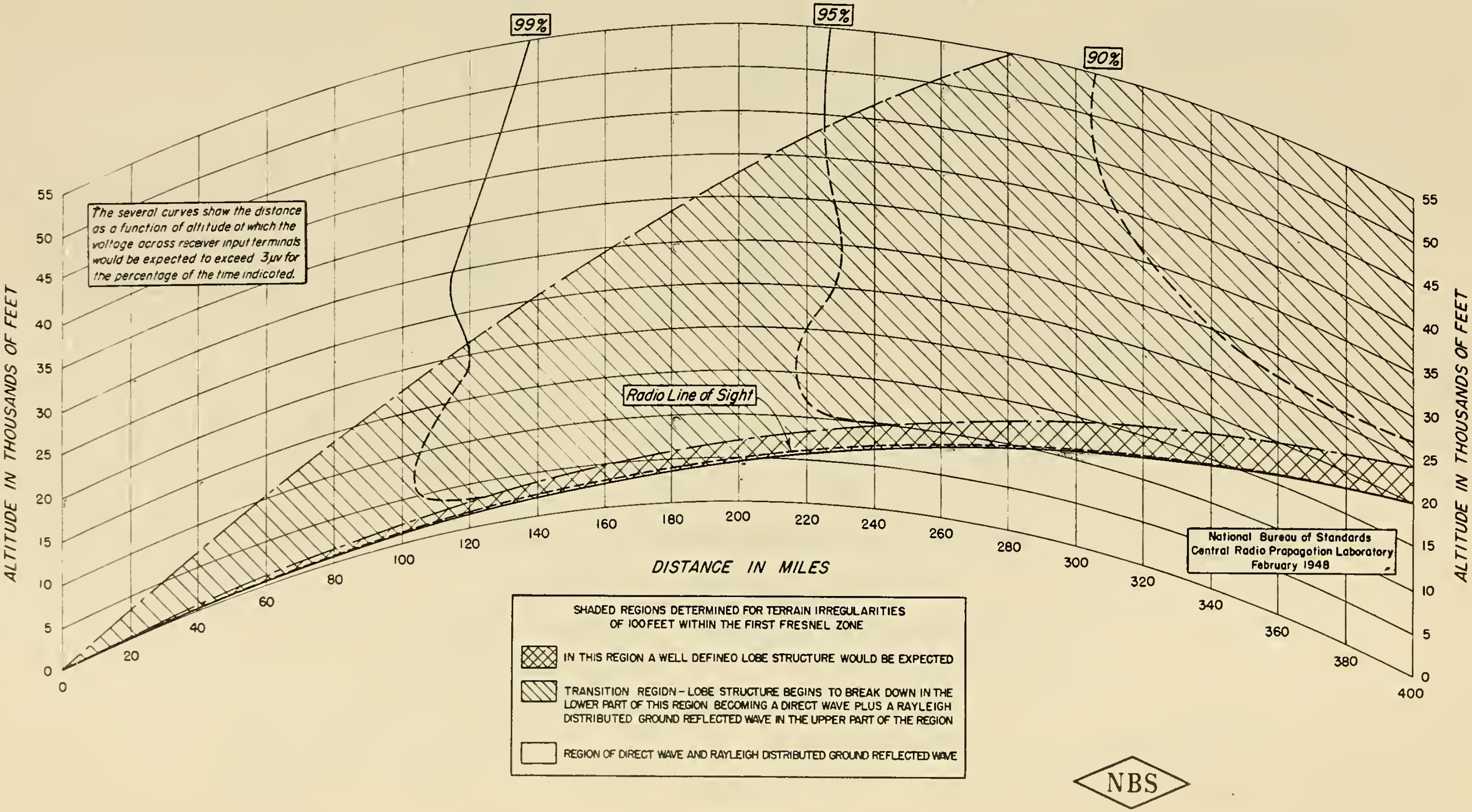


FIGURE 5

RECEIVED FIELD DISTRIBUTION FOR AIR TO AIR COMMUNICATION ON 328 Mc/s OVER IRREGULAR TERRAIN FOR TWO AIRCRAFT FLYING AT THE SAME ALTITUDE

TRANSMITTING ANTENNA GAIN: 1.64 (relative to an isotropic); POWER: 6 WATTS; VERTICAL POLARIZATION

RECEIVING ANTENNA GAIN: 1.64

ASSUMED COMMUNICATION SYSTEM LOSS: 6 db

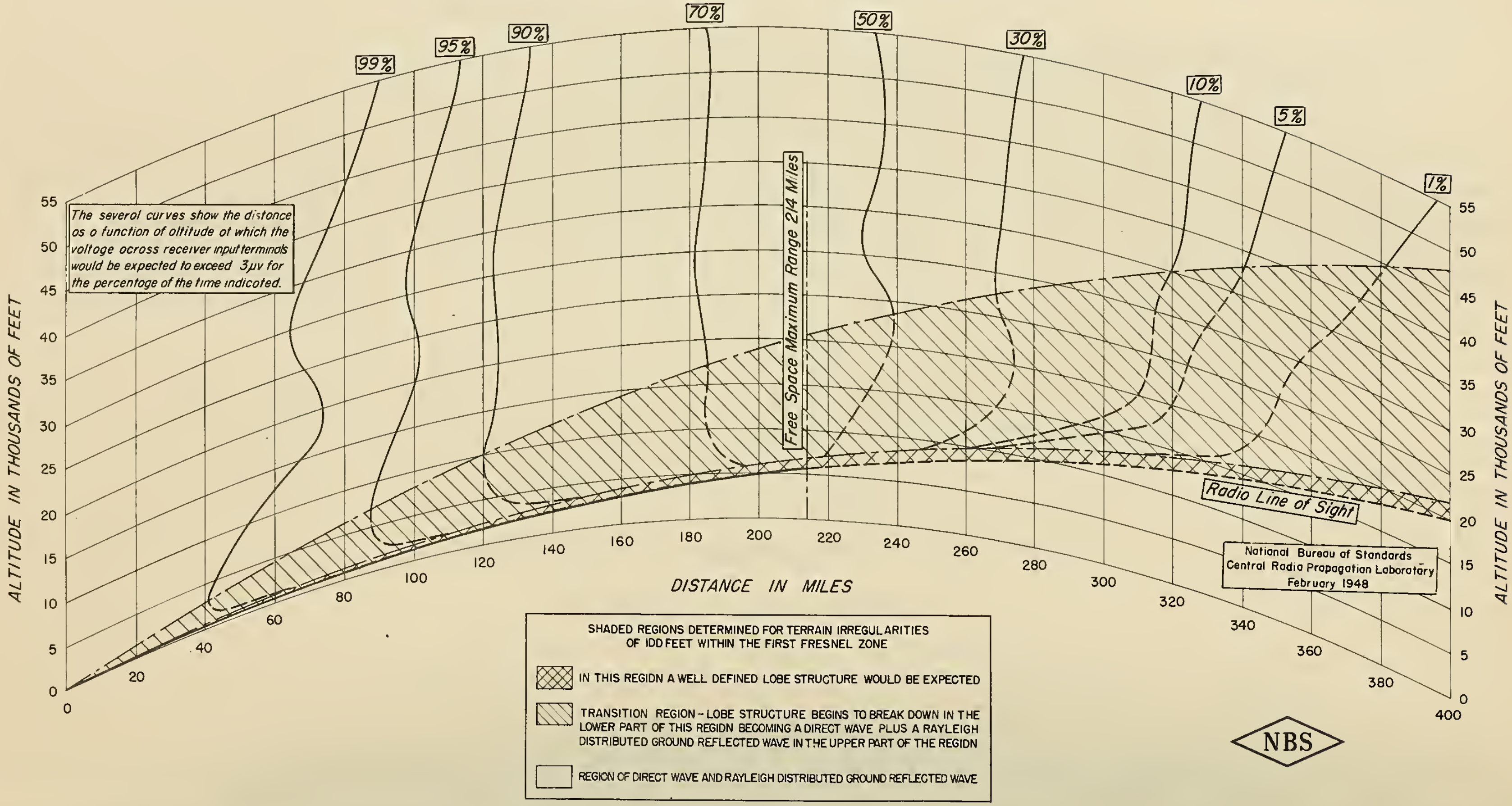


FIGURE 6

328 Mc RADIATION PATTERN FOR GROUND TO AIR COMMUNICATION OVER A SMOOTH SPHERICAL EARTH

TRANSMITTING ANTENNA GAIN; 4.29 (relative to an isotropic);
POWER: 13 WATTS; HEIGHT: 48 FEET; VERTICAL POLARIZATION

RECEIVING ANTENNA GAIN: 1.64

ASSUMED COMMUNICATION SYSTEM LOSS: 6 db

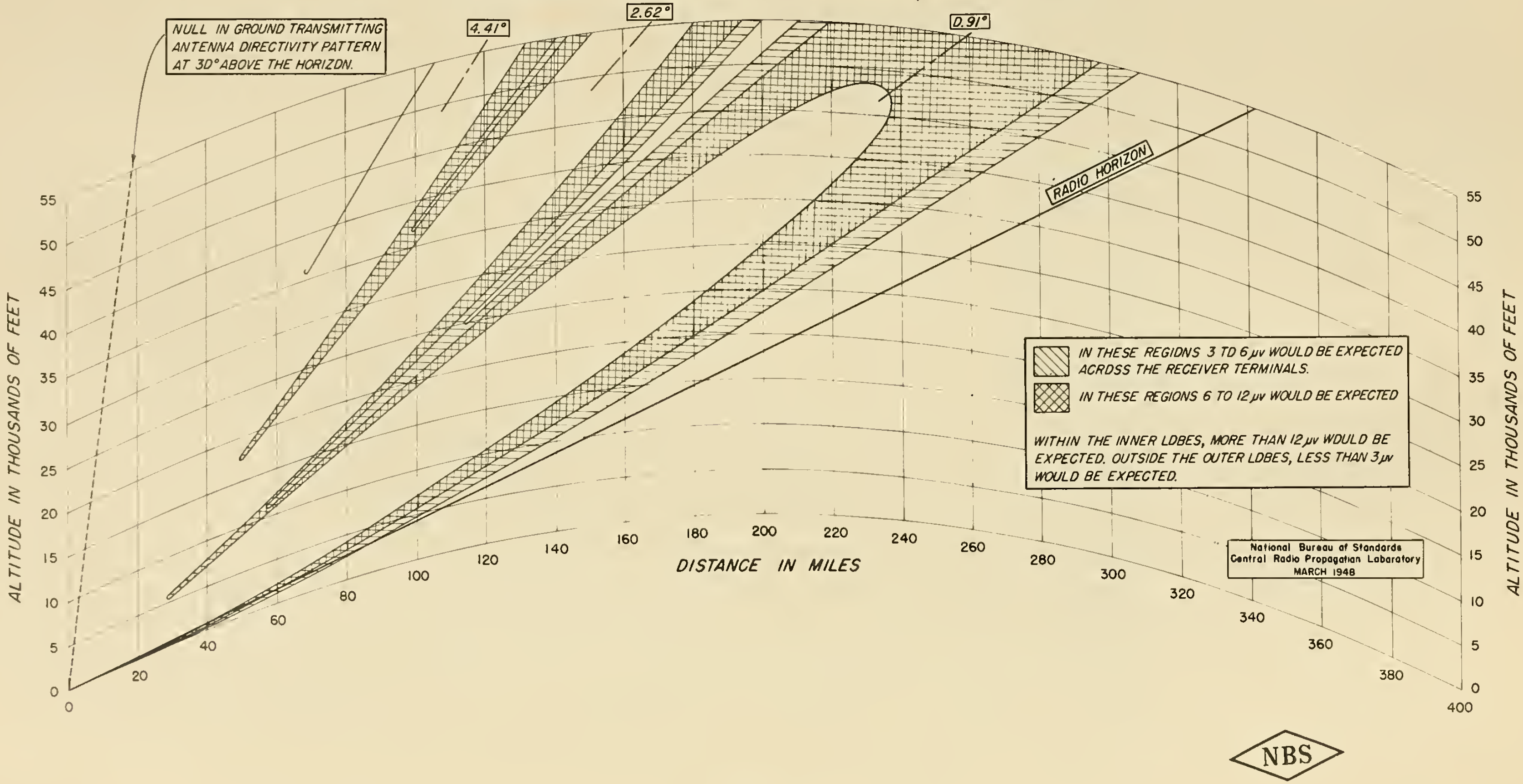


FIGURE 7

Supplement XX

ANALYSIS OF THE GROUND WAVE AND TROPOSPHERIC WAVE FIELD INTENSITY VARIATIONS AT A DISTANCE FAR BEYOND THE LINE-OF-SIGHT FOR AN FM BROADCASTING STATION OPERATING ON 99.7 Mc

By

R. S. Kirby

Supplement XX

ANALYSIS OF THE GROUND WAVE AND TROPOSPHERIC WAVE FIELD INTENSITY VARIATIONS AT A DISTANCE FAR BEYOND THE LINE-OF-SIGHT FOR AN FM BROADCASTING STATION OPERATING ON 99.7 Mc

By

Robert S. Kirby
National Bureau of Standards
Boulder, Colorado

For the purpose of obtaining a better understanding of the nature of the variation in field intensities at large distances far beyond the line-of-sight in the frequency modulation broadcast band, field intenisty recorders were installed at the National Bureau of Standards in Washington, D.C., late in 1947. These recorders consisted of Hallicrafters' Model SX-42 AM-FM receivers so modified that the input signal voltage could be recorded on an Esterline Angus recording milliameter. Calibration of the recordings was effected by the use of a suitable signal generator, several types of which were used.

Continuous recordings were made of the field intensities of several frequency modulation broadcast stations. One of the most complete records is that of frequency modulation broadcast station WSAP-FM in Portsmouth, Virginia, broadcasting on a frequency of 99.7 Mc and at an airline distance of 151 miles from the receiving location at the National Bureau of Standards. The terrain profile over this path is shown in the attached figure. The center of the WSAP-FM transmitting array is 356 feet above sea level, and the average terrain in the direction of Washington, D.C., is essentially water at sea level to a distance of about 11 miles. The effective radiated power (i.e. radiated power times antenna power gain relative to a half wave dipole) in this direction was 49 kilowatts to July 17, 1949, and from this date on, 100 kilowatts. At the receiving end a three-element Yagi array was used with a gain of 9.3 decibels with respect to an isotropic antenna; this was erected on the roof of the Northwest building of the National Bureau of Standards. This receiving array was 80 feet above the ground level as shown in the figure. On

September 10, 1948 a recording site was set up in the West building, and the records obtained from this site were used from this date on. The receiving antenna here consisted of a half-wave dipole about 15 feet higher above sea level but again only about 80 feet above the ground which was about 15 feet higher at the latter location. This location was approximately 200 yards to the southwest of the original location.

The calibration technique consisted of comparing the meter deflection from an unknown input voltage with that of a known input voltage from the signal generator and applying a calibration factor to obtain readings in terms of microvolts-per-meter.

The data were analyzed by tabulating the median field intensity for each hour. A total of 3071 hours were thus analyzed for the WSAP-FM transmissions between April 30, 1948 and January 28, 1949. The hours used are shown in the tabulation at the end of this report.

The distribution with time of the hourly median field intensity was plotted separately for each hour of the day and then an overall distribution was determined from these separate hourly distributions by giving each hour for which distribution curves were available equal weight, regardless of the number of days for which measurements were made at the various individual hours. In all cases shown in the tabulation the value of field intensity used refers to an effective radiated power of 100 kilowatts. For the period in which the effective radiated power was 49 kilowatts, a correction factor was applied to the data. The results of this analysis are tabulated in terms of the value of field intensity that was exceeded for the given percentages of time. This particular analysis of these data was prepared to assist in the work of the Ad Hoc Committee appointed by the FCC to study VHF field intensity propagation.

The following memebers of CRPL participated actively in obtaining and analyzing these data:

Mr. M. Blum
Mr. H. Bussey
Mr. J.H. Chisholm
Mr. E.G. Cowen

Mr. J. Harman
Mr. L. C. Huffman
Mr. V. LaBolle
Dr. W. Miller
Mr. E. Y. Mitoma
Mr. D. L. Randall
Mr. H. Staras
Mr. K. F. Tritabaugh
Mr. W. W. Warren
Mr. J. W. Whitmore
Mr. W. P. Witkowski

Number of days field intensity record of WSAP-FM was analyzed by hour of day during the period April 30, 1948 to January 28, 1949.

Hour	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Total
00-01	0	5	7	19	22	22	24	18	23	16	156
01-06	Off the Air										
06-07	0	4	7	16	24	22	25	19	25	17	159
07-08	0	4	7	16	25	22	25	19	25	17	160
08-09	0	6	8	18	29	23	29	22	27	19	181
09-10	1	15	8	19	28	22	29	24	28	19	193
10-11	1	15	9	18	29	22	31	24	28	18	195
11-12	1	15	9	21	29	21	31	26	28	18	199
12-13	1	15	9	20	29	22	31	26	28	18	199
13-14	1	14	9	20	29	22	31	25	28	15	194
14-15	1	14	9	21	29	24	31	25	27	17	198
15-16	1	12	9	20	29	23	30	24	26	18	192
16-17	1	14	9	21	29	23	23	19	16	8	163
17-18	1	14	9	21	30	23	21	0*	1	0*	120
18-19	1	14	9	20	30	23	20	0*	0*	0*	117
19-20	1	14	9	21	30	23	20	0*	0*	0*	118
20-21	1	14	9	22	30	22	20	0*	0*	0*	118
21-22	1	14	9	22	30	22	20	0*	0*	0*	118
22-23	0	6	8	22	30	22	20	0*	1	0*	109
23-24	0	4	7	22	30	23	30	23	26	17	182
Total	13	213	160	379	541	426	491	294	337	217	3071

* Record not available at these hours during these months because of interference from WCFM operating on 99.5 Mc.

Distribution of hourly median values of field intensity for 100 kw transmission from WSAP-FM, Portsmouth, Va., 99.7 Mc. as received at National Bureau of Standards, Washington, D. C.

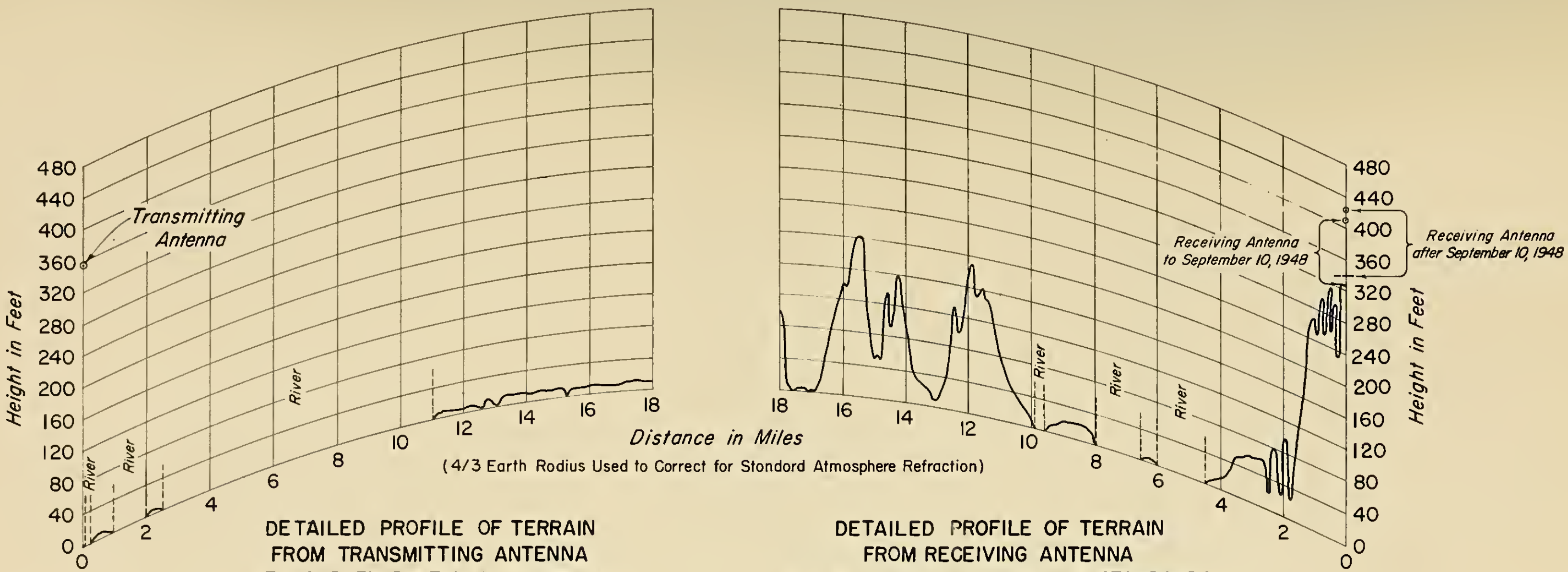
Hour	1%	10%	50%	90%	99%
00-01	520	98	27.5	9.1	3.5*
01-06	Off the Air				
06-07	255	106	29.5	7.8	2.8*
07-08	222	109	29.0	8.1	2.7*
08-09	380	128	28.5	8.8	3.0*
09-10	395	102	22.0	8.3	3.0*
10-11	270	74	21.0	7.3	2.7*
11-12	182	60	17.5	6.2	2.6*
12-13	148	53	16.0	6.0	2.7*
13-14	123	50	15.0	5.7	2.8*
14-15	121	56	13.9	5.4	2.4*
15-16	138	57	15.2	5.9	2.9*
16-17	180	57	14.3	4.8	2.1*
17-18	186	38	13.1	4.6	2.1*
18-19	440	42	12.5	5.0	2.1*
19-20	155	45	14.7	4.9	2.2*
20-21	180	53	15.5	4.1	1.8*
21-22	320	52	18.0	5.1	2.3*
22-23	180	67	23.0	6.0	2.1*
23-24	440	87	22.5	7.6	2.6*

Total distribution of hourly median values of field intensity (giving equal weight to each hour)

1%	10%	50%	90%	99%
250**	71	18.5	5.9	2.2*

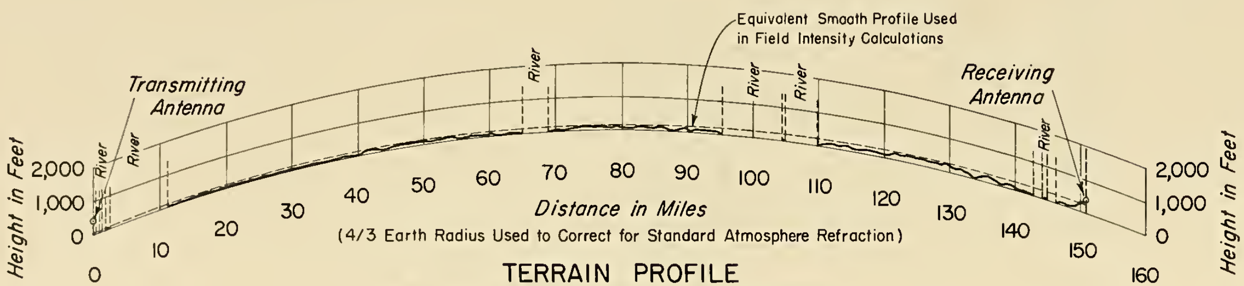
*Extrapolated values.

**Some extrapolated points used to obtain this value.



DETAILED PROFILE OF TERRAIN
FROM TRANSMITTING ANTENNA
AT WSAP-FM PORTSMOUTH, VIRGINIA

DETAILED PROFILE OF TERRAIN
FROM RECEIVING ANTENNA
AT THE NATIONAL BUREAU OF STANDARDS



TERRAIN PROFILE
WSAP-FM PORTSMOUTH, VIRGINIA
TO
THE NATIONAL BUREAU OF STANDARDS

NBS

National Bureau of Standards
Central Radio Propagation Laboratory
February 1948
Revised February 1949

Supplement XXI

PROPAGATION OVER ROUGH TERRAIN

By

K. A. Norton

Originally presented at U.S. NEL Symposium, July 25, 1949, NE 120301, Report 173, Problem NEL 1A1, p. 101, U.S. Navy Electronics Laboratory, San Diego, California.

Supplement XXI

PROPAGATION OVER ROUGH TERRAIN

By

Kenneth A. Norton
National Bureau of Standards
Boulder, Colorado

It is intended here to describe some of the characteristics of two important mathematical tools useful in statistical predictions of ground-wave propagation, and to demonstrate, by an example, their applicability to the description of radio propagation over irregular terrain. It should be stressed at the outset that this is but an interim report on methods which have been found useful in a field in which new and better methods of analysis are being developed almost daily. The methods to be described have been useful in stimulating thinking on this subject and are passed along at this time merely as a progress report and not as completed research.

The Rayleigh Distribution

Lord Rayleigh solved the problem of determining the probability distribution of the intensity and phase of the resultant vector, E_s, obtained by adding together, with random relative phase, a large number of vectors, E_1, E_2, and so forth up to E_n, as shown in figure 1. If E_r^2 is a constant, i.e., the mean energy in the reflected wave is a constant, $E_i^2 << E_r^2$ for i = 1 to n, the phase of each component vector E_i is random, and n is sufficiently large, then (1) the probability that the resultant E_s will be greater than x is given by the cumulative Rayleigh distribution, $P(E_s > x) = \exp(-x^2/E_r^2)$, and (2) the phase of the resultant vector E_s will also be random.

Figure 2 shows the result of the deviations from one of the above four requirements: the effect of reducing the number, n, of the component vectors. This particular graph paper has been constructed in such a way that a Rayleigh distributed vector of amplitude, E_s, will be represented by a straight line with a slope of -1. The distributions shown here are for n unit vectors added with random relative phase. Thus, the root-sum-square value in each case is equal to the square root of n. The ordinate gives E_s divided by this root-sum-square value. It can easily be shown that the root-mean-square value of E_s is equal to $\sqrt{n}$. The maximum amplitude of the resultant of n vectors is, of course, simply equal to n. The rapid approach to a Rayleigh distribution is clearly shown by the curves for n = 2, 3, and 4. Throughout the range of this particular graph, that is, from a value of 0.01 per cent up to 99.99 per cent, the distribution for n = 10 deviates from the true Rayleigh distribution by less than the width of the line. It is important to notice that a complete specification of a Rayleigh distributed wave can be made in terms of a single parameter which is, in effect, a measure of the total energy in the wave. This single parameter might be the rms value which is exceeded by 36.8 per cent of all the values which the amplitude of E_s may have. A Rayleigh-distributed amplitude could equally well be defined in terms of a value exceeded for some specified percentage of the time; for example, the median, or 50 per cent amplitude is equal to 0.8326 times the rms value of E_s.

Figure 3 considers the distribution of the instantaneous voltage, v, to be expected from a Rayleigh-distributed vector with amplitude, E_s, and random phase $(\omega t + \phi)$. If $p(E_s > x) = \exp -(x^2/E_r{}^2)$, then

$$p\,(v > X) = \frac{1}{\sqrt{2\pi}} \int_{(X\sqrt{2}/E_r)}^{\infty} \exp\,(-y^2/2)dy.$$

We find that this voltage is distributed in a normal distribution with a mean value of zero and a standard deviation $E_r/\sqrt{2}$, where E_r is the rms value of E_s.

In many radio propagation studies, the received fields are rectified before being recorded, and thus continuous recorders ordinarily provide records of the variations of the inherently positive amplitudes, E_s, of the envelope rather than of the instantaneous voltage, v, which may be either positive or negative. For this reason, in the remainder of the discussion of the Rayleigh distribution, no further mention will be made of the instantaneous voltage v. This brief discussion of the normal distribution of instantaneous voltage was presented because it is sometimes confused with Rayleigh distribution of the amplitude of E_s, and in this paper only the latter distribution will be used.

Application of the Rayleigh Theory

The application of the above theory to a problem of ground-wave propagation over irregular terrain can now be discussed. It is well known that the resultant field, E, to be expected in propagation over a smooth earth at points within the line-of-sight, may be considered to be the vector sum of a direct wave, E_o, plus a ground-reflected wave, E_g, as shown in figure 4a. Over a smooth spherical earth, the ground-reflected wave will be weaker than the direct wave, not only because some of its energy is lost by absorption, but also because of a divergence of the energy on reflection at the curved surface of the earth.

Over a rough earth, it is convenient to consider the ground-reflected wave to be the resultant of a large number of component vectors with random relative phases as indicated in figure 4b. Thus, each component vector may be considered to have its phase determined by the length of the path from the transmitting antenna to the corresponding bounce point and thence to the receiving antenna. The bounce points on the rough reflecting surface, corresponding to the several component vectors, are the locations on the surface for which the phase is stationary; that is, the path length is either a minimum or a maximum. When the earth is sufficiently rough, the frequency sufficiently high, and the angle of incidence sufficiently small--that is, not too near to grazing incidence--it will be found that the relative phases of the individual component vectors will be comparable to or greater than 2π radians. Under these circumstances, all values of the relative phase between the component vectors are equally likely. The above description of the ground-reflected wave over a rough earth is simply that of a Rayleigh distributed wave. It has already been seen that such a wave is completely described by its rms amplitude, E_r. If there were no additional loss in the ground-reflected wave energy due to roughness, this rms amplitude, E_r, would simply be equal to the amplitude, E_g, of the wave reflected from the smooth earth. For the present, it will be sufficient to let $E_r^2 \equiv kE_o^2 = E_1^2 + E_2^2 + E_3^2 + E_4^2 + E_5^2 + E_6^2$, where k is a constant, usually less than unity, which denotes the energy in the rough-earth ground-reflected wave relative to that in the direct wave.

It might at first sight appear that the vector sum of the direct wave, E_o, plus the Rayleigh-distributed, rough-earth, ground-reflected wave would also be distributed in a Rayleigh distribution, but this does not follow because of the fact that the component vector, E_o, is, in this case, not small compared to the root-sum-square value of all of the components.

In figure 5 is shown the expected distribution of a resultant when the energy of one of the individual component vectors, represented by E_o^2, is not small in comparison to the total energy represented by $(E_o^2 + E_r^2)$. It will be noted that the resultant, E, is Rayleigh-distributed only for very large values of k, that is, only for very large values of multiple-component, Rayleigh-distribution energy compared to the single-component, direct-wave energy. Such large values of k would be expected only in an unusual situation where the direct wave is suppressed, for example, by means of a transmitting array directed away from the actual receiving antenna toward the center of gravity of the images of the receiving antenna in the rough ground.

As k becomes smaller and smaller, that is, as the random energy becomes small in comparison to the direct wave energy, the slope of the distribution becomes smaller. This should be noted in connection with later experimental results.

The results shown here can also be used in the case where the individual component vectors do not have completely random relative phases. Consider, for example, the situation where the individual vectors have phases which vary at random only through a restricted total range of phase variation much less than 2π. In this case, each individual component vector can be resolved into two other components, one of which can be considered to consist of coherent, specularly reflected energy, and the other to consist of scattered energy. The coherent components can be added to give the vector designated at E_o (in figure 5), while the root-sum-square value of the incoherent components is simply E_r. Thus, it becomes possible to determine the distribution of the amplitude of a wave reflected at a moderately rough surface, simply by identifying a specularly reflected component, E_o, and a scattered component, E_r.

Experimental Applications

Some of the concepts just described can best be illustrated by applying them to the explanation of the results of a propagation experiment illustrated in figure 6. In this experiment, two aircraft flew away from each other at an altitude of 9800 feet. Field intensity measurements were made in one of the aircraft by the Collins Radio Company of the simultaneous transmissions from the other on 123 Mc and 328 Mc. Two flights were made, one with the midpoint of the transmission path on land in the Midwest, and the other with the midpoint on Lake Michigan.

Calculations indicated that regular fading was occurring at the rate which would be expected for interference between a direct and a ground-reflected wave. Under these conditions, the field intensity maxima should be equal in amplitude to the sum of the direct wave amplitude plus the ground-reflected wave amplitude, and the observed minima equal to the difference in these two amplitudes. By measuring these maxima and minima, it is possible to calculate the value of the ground reflection coefficient. A separate value of this ground reflection coefficient can be obtained from each maximum and succeeding minimum.

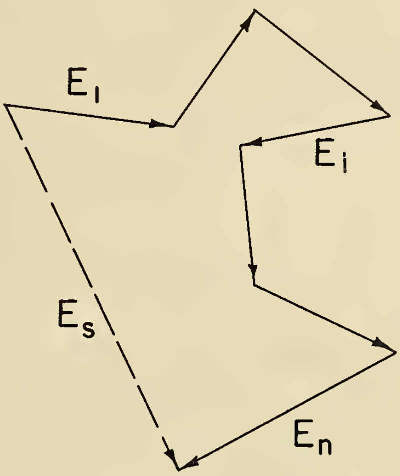
Figure 7 shows the distribution of the ground-reflection coefficients determined in this way for these two distance ranges. The lines having the slope of -1 are the Rayleigh distributions determined from the rms value of the reflection coefficient and are given by $p = 100 \exp \left[-(E_R/E_D)^2/(E_R'/E_D')^2\right]$. It will be noted that the measurements are in good agreement with the theory at the shorter of the two distance ranges corresponding to more nearly oblique incidence on the ground (the angle at the earth's surface is 3 degrees). The data at the larger range did not agree as well with the Rayleigh distribution, presumably because of the larger angle of incidence, nearly 89 degrees in this case. Thus, it appears that the ground is beginning to appear more nearly smooth to the radio waves at this grazing angle of only about 1 degree. By using the curves shown in figure 5, it is possible to estimate from the slope of this curve the relative amount of the energy scattered and specularly reflected. In this particular case, it has been determined that the energy received by specular reflection is about six times the scattered energy. It should be noted that the rms reflection coefficient is somewhat larger at the larger range.

The magnitudes of the ground-reflection coefficients will now be considered. In figure 8 the points plotted represent rms values of the ground-reflection coefficients. Each point is the rms value obtained from about 40 separate determinations. The circles joined by a dashed curve denote values measured over land on 328 Mc, while the crosses joined by a dotted curve represent values measured over land on 123 Mc. The upper solid curve corresponds to a reflection coefficient calculated on the assumption that the earth is smooth and may be represented by a dielectric constant equal to 30; thus, these values correspond to the product of a plane-wave reflection coefficient multiplied by a divergence factor to allow for the effects of earth's curvature in spreading the energy in the reflected wave. The low values of reflection coefficient at the shorter distances are caused by earth absorption near the pseudo-Brewster angle, while the low values at large distances are due to the larger divergence expected near grazing incidence. The lower solid curve corresponds to Lambert's law of reflection from diffuse surfaces; thus, according to this law, the energy reflected is proportional to the cosine of the angle of incidence. Lambert's law does not specify the magnitude of the reflection; this has been assumed in these curves to be the plane-earth reflection coefficient. Thus, it is assumed that the divergence factor, D, over a smooth sphere should be replaced by the factor, $\sqrt{\cos\phi}$, for a perfectly rough earth, the latter corresponding to a much greater divergence of the energy due to scattering. For the transition between the perfectly smooth and perfectly rough calculations,

$$|R| = \left[D^2\cos^2\left(\frac{4\pi\,\Delta h\cos\phi}{\lambda}\right) + \cos\phi\,\sin^2\left(\frac{4\pi\Delta h\cos\phi}{\lambda}\right)\right]^{1/2}$$

In figure 9 are values similar to those of figure 8, but representing propagation over Lake Michigan. In this case, it was assumed that the dielectric constant should be 80, and it is noted that the pseudo-Brewster effect occurs now at a larger range. The large value of $\Delta h = 10$ ft, which seems to agree best with experimental data, is difficult to believe unless Lake Michigan was unusually rough. However, it is not known how far out over the lake the measurements were made, and it may be that shore reflections played a large part in the measured results.

THE RAYLEIGH DISTRIBUTION OR RANDOM WALK



$$E_r^2 = E_1^2 + \cdots E_i^2 + \cdots + E_n^2$$

if (1) E_r^2 is a constant, i.e. the mean energy in the reflected wave is a constant

and (2) $E_i^2 << E_r^2$ for i = 1 to n

and (3) The phase of each component vector E_i is random

and (4) n is sufficiently large

then (1) The probability that the resultant E_s will be greater than X is given by the cumulative Rayleigh distribution:

$$P_{(E_s > X)} = e^{-(X^2/E_r^2)}$$

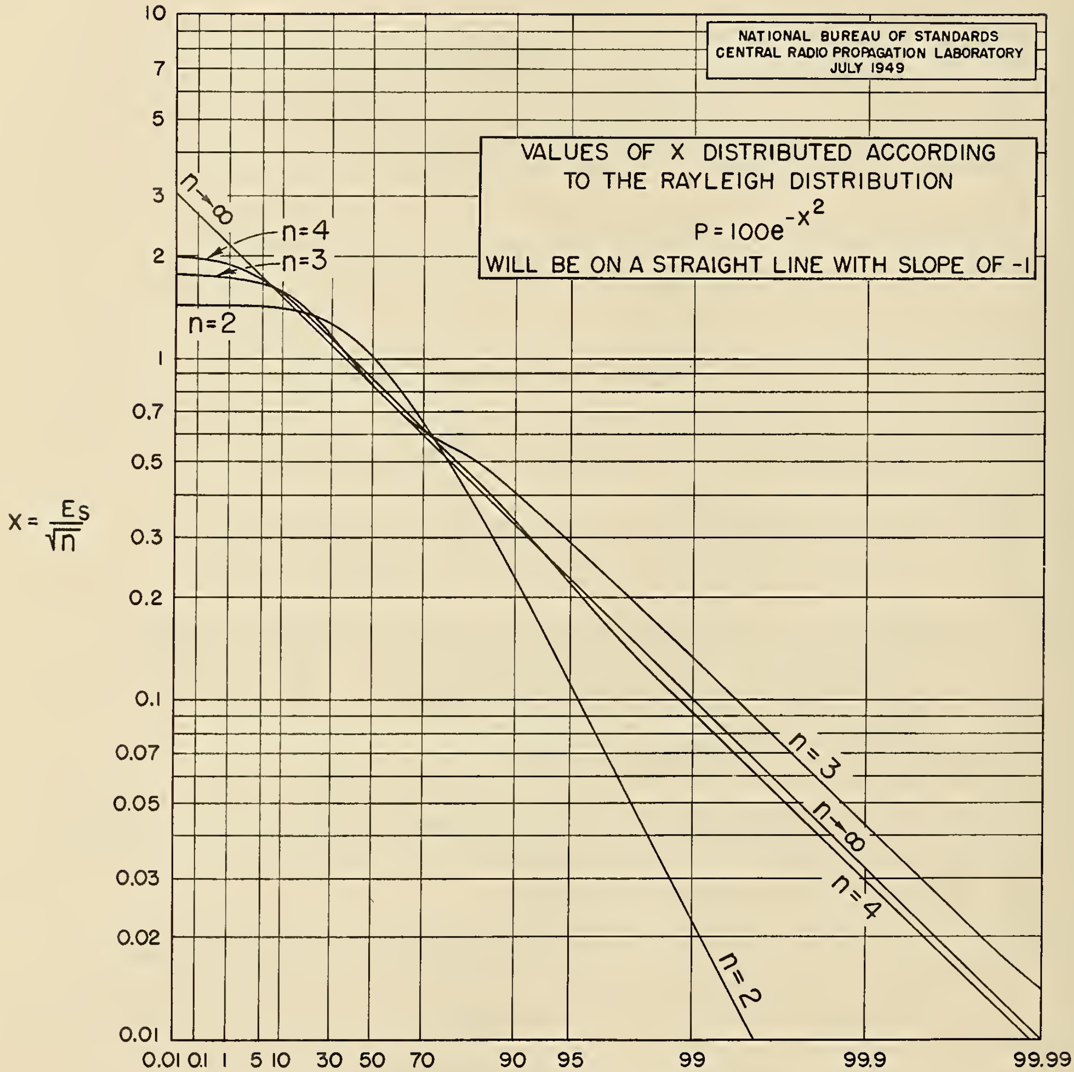
and (2) The phase of the resultant vector E_s will also be random

NBS

NATIONAL BUREAU OF STANDARDS
CENTRAL RADIO PROPAGATION LABORATORY
MAY 1949

Figure 1

THE RESULTANT OF n UNIT VECTORS WITH RANDOM RELATIVE PHASE

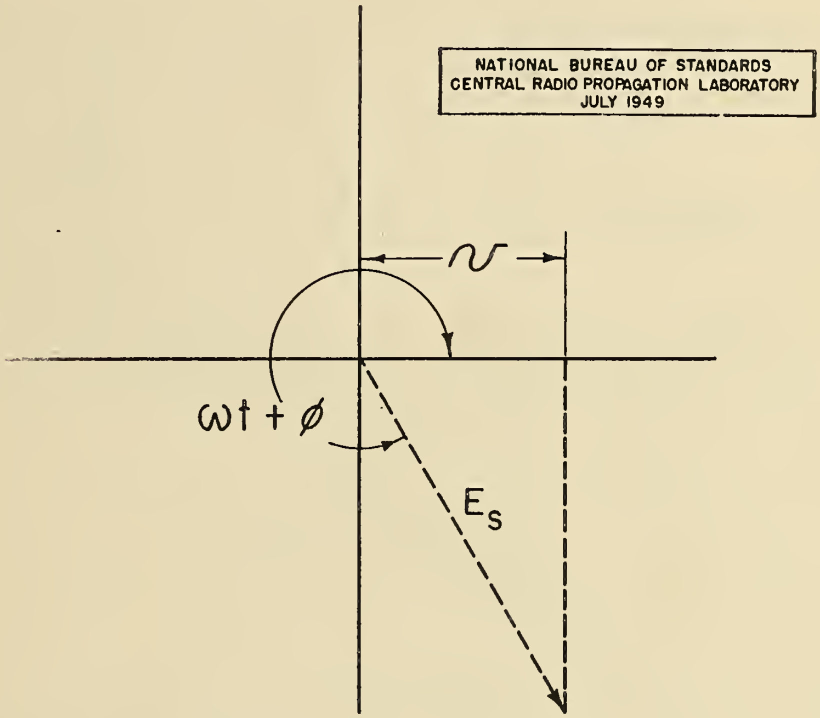


EXPECTED PERCENTAGE OF THE RESULTANTS WITH A FIELD INTENSITY GREATER THAN THE ORDINATE

NBS

Figure 2

THE NORMAL DISTRIBUTION OF VOLTAGE, v, DERIVED FROM A RAYLEIGH DISTRIBUTED VECTOR OF AMPLITUDE E_s



$$v = E_s \cos(\omega t + \phi)$$

if (1) $p(E_s > X) = e^{-(X^2/E_r^2)}$

and (2) all values of $(\omega t + \phi)$ are equally likely.

then $p(v > X) = \frac{1}{\sqrt{2\pi}} \int_{(X\sqrt{2}/E_r)}^{\infty} e^{-y^2/2} dy$

mean value of $v = 0$

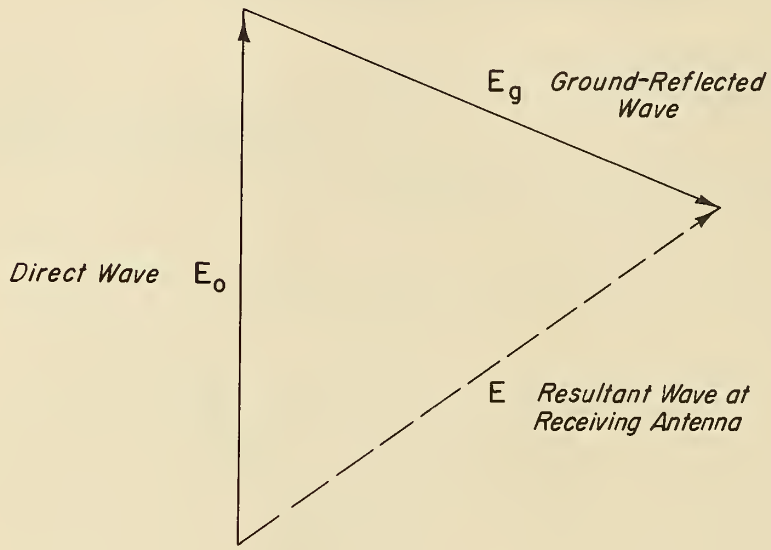
standard deviation of v = root-mean-square voltage = $E_r/\sqrt{2}$

E_r = root-mean-square value of the amplitude E_s

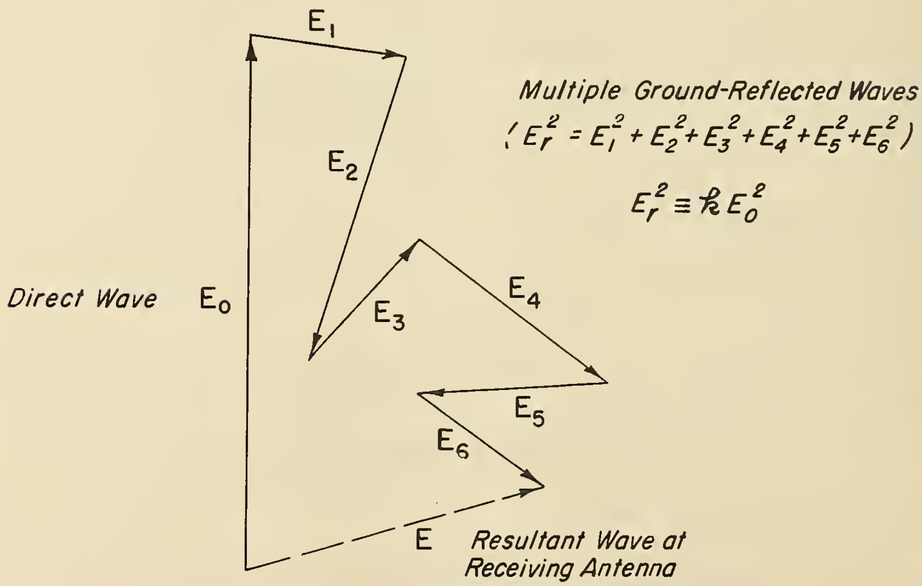
Figure 3

NBS

VECTOR REPRESENTATION OF DIRECT AND GROUND-REFLECTED WAVES FOR SMOOTH OR ROUGH EARTH



a. SMOOTH EARTH

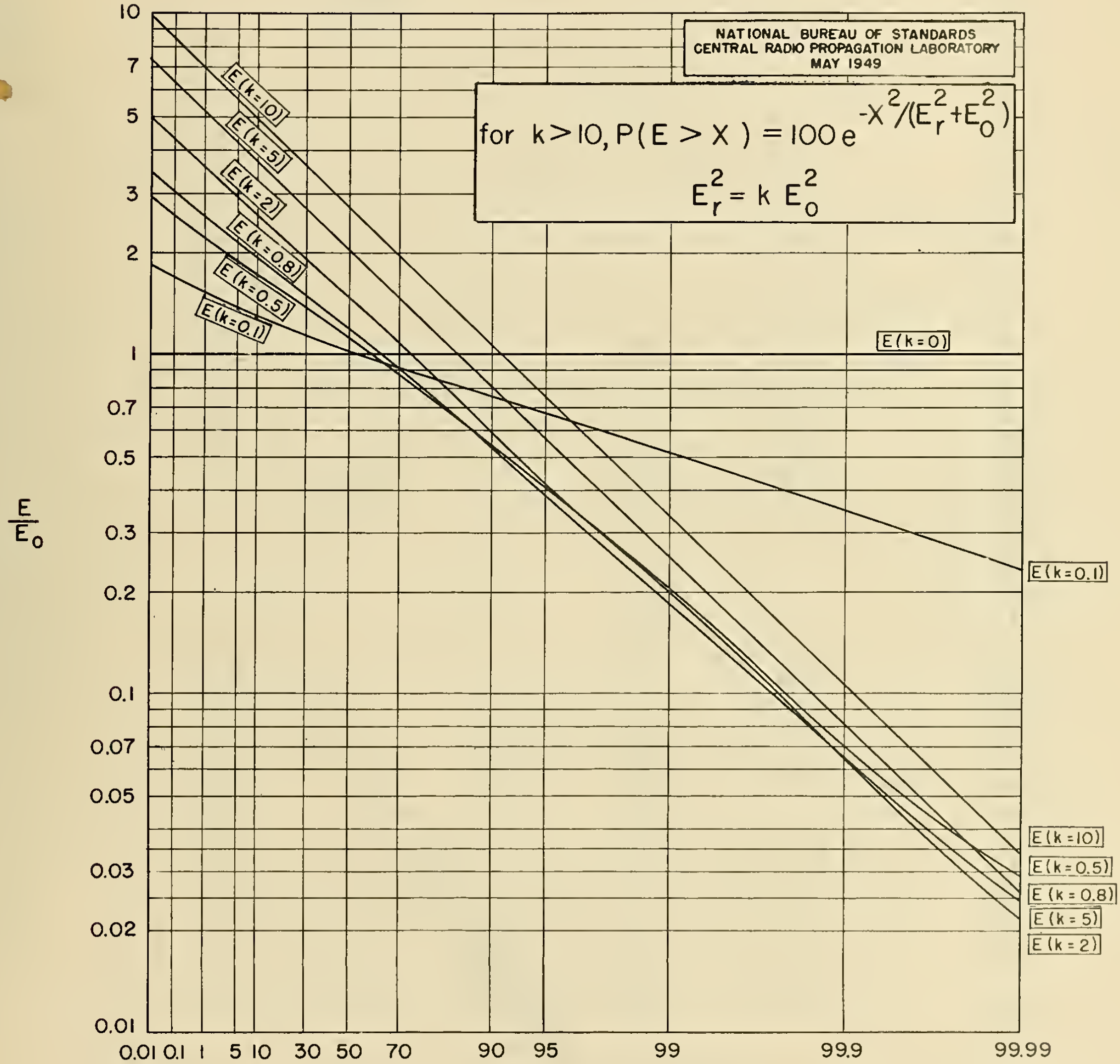


b. ROUGH EARTH

Figure 4

NATIONAL BUREAU OF STANDARDS
CENTRAL RADIO PROPAGATION LABORATORY
MAY 1949

THE SUM OF A DIRECT WAVE PLUS A RAYLEIGH DISTRIBUTED GROUND-REFLECTED WAVE



EXPECTED PERCENTAGE OF THE RECEIVING LOCATIONS WITH A RESULTANT INTENSITY GREATER THAN THE ORDINATE VALUE

NBS

Figure 5

GEOMETRY OF AIR-TO-AIR PROPAGATION EXPERIMENT

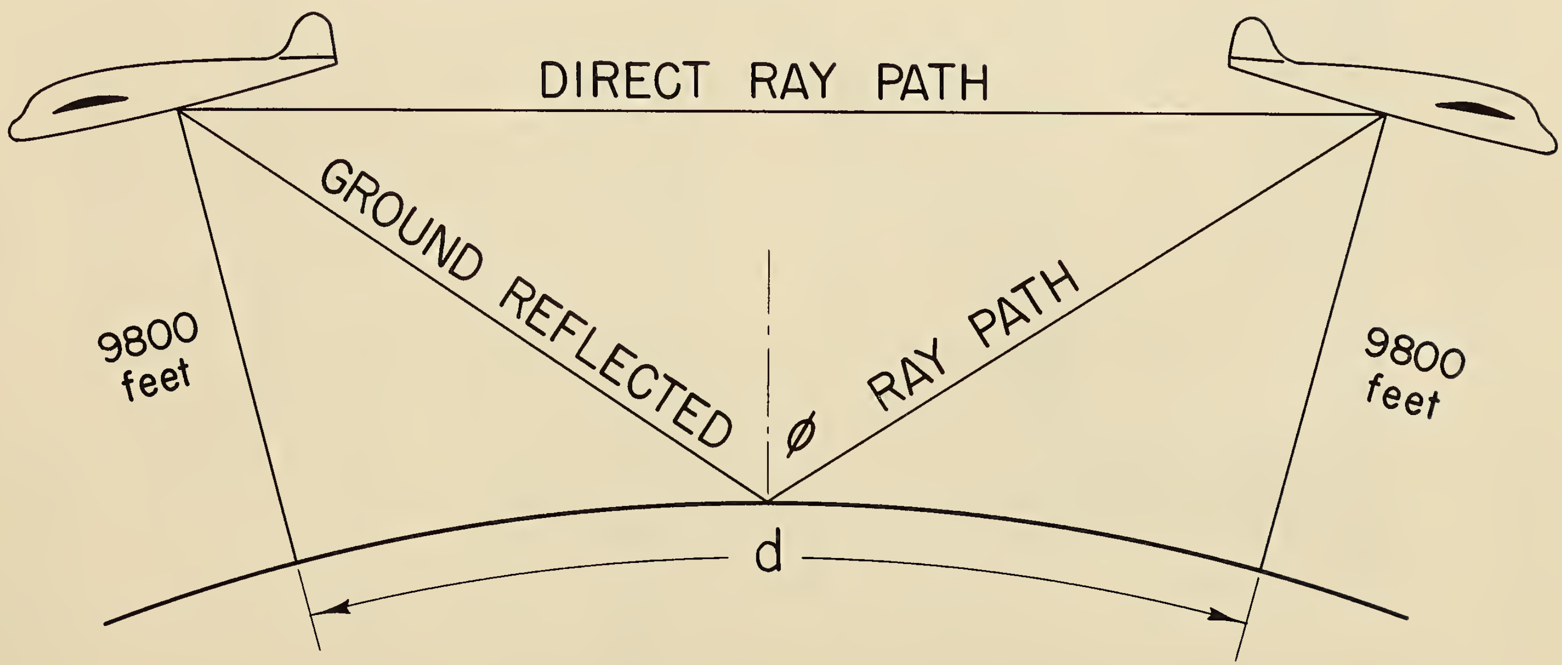
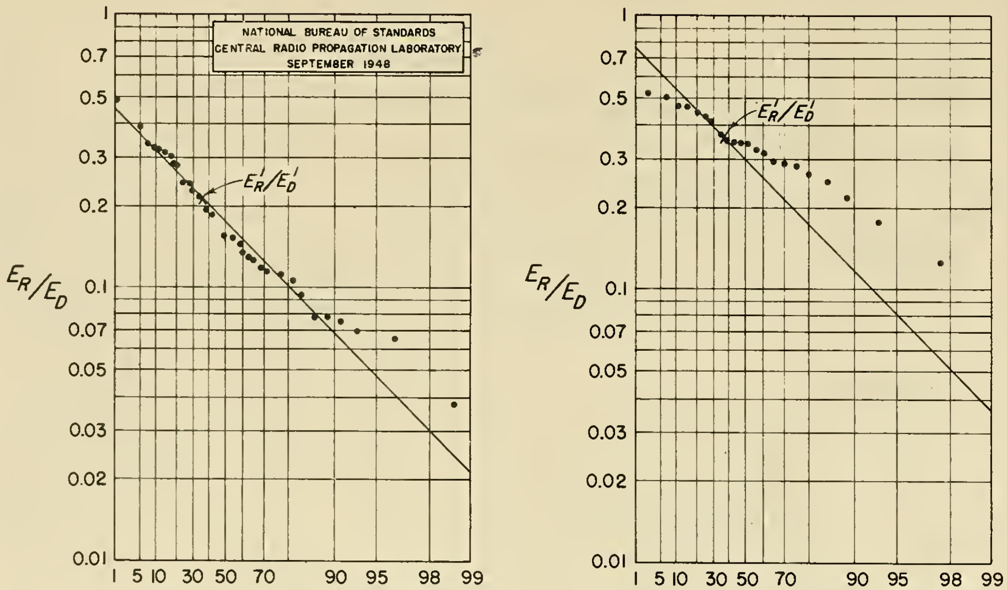


Figure 6

DISTRIBUTION OF OBSERVED EFFECTIVE INTENSITY OF GROUND REFLECTED WAVE, E_R, RELATIVE TO THE DIRECT WAVE, E_D, FOR TWO AIRCRAFT FLYING OVER IRREGULAR TERRAIN

FREQUENCY 328 MC/S; ALTITUDE 10,000 FEET



PERCENTAGE OF THE DISTANCE WITH RATIOS HIGHER THAN THE ORDINATE VALUE

60 - 70 MILES

PERCENTAGE OF THE DISTANCE WITH RATIOS HIGHER THAN THE ORDINATE VALUE

128 - 148 MILES

Values of E_R/E_D distributed in accordance with the Rayleigh distribution

$$P = 100\, e^{-(E_R/E_D)^2/(E_R'/E_D')^2}$$

would be on the straight line with slope −1

NBS

(From data taken by Collins Radio Company, Cedar Rapids, Iowa)

Figure 7

EFFECTIVE REFLECTION COEFFICIENT OF THE GROUND FOR AIR-TO-AIR RADIO PROPAGATION

BOTH AIRCRAFT AT AN ALTITUDE OF 9800 FEET OVER LAND
VERTICAL POLARIZATION

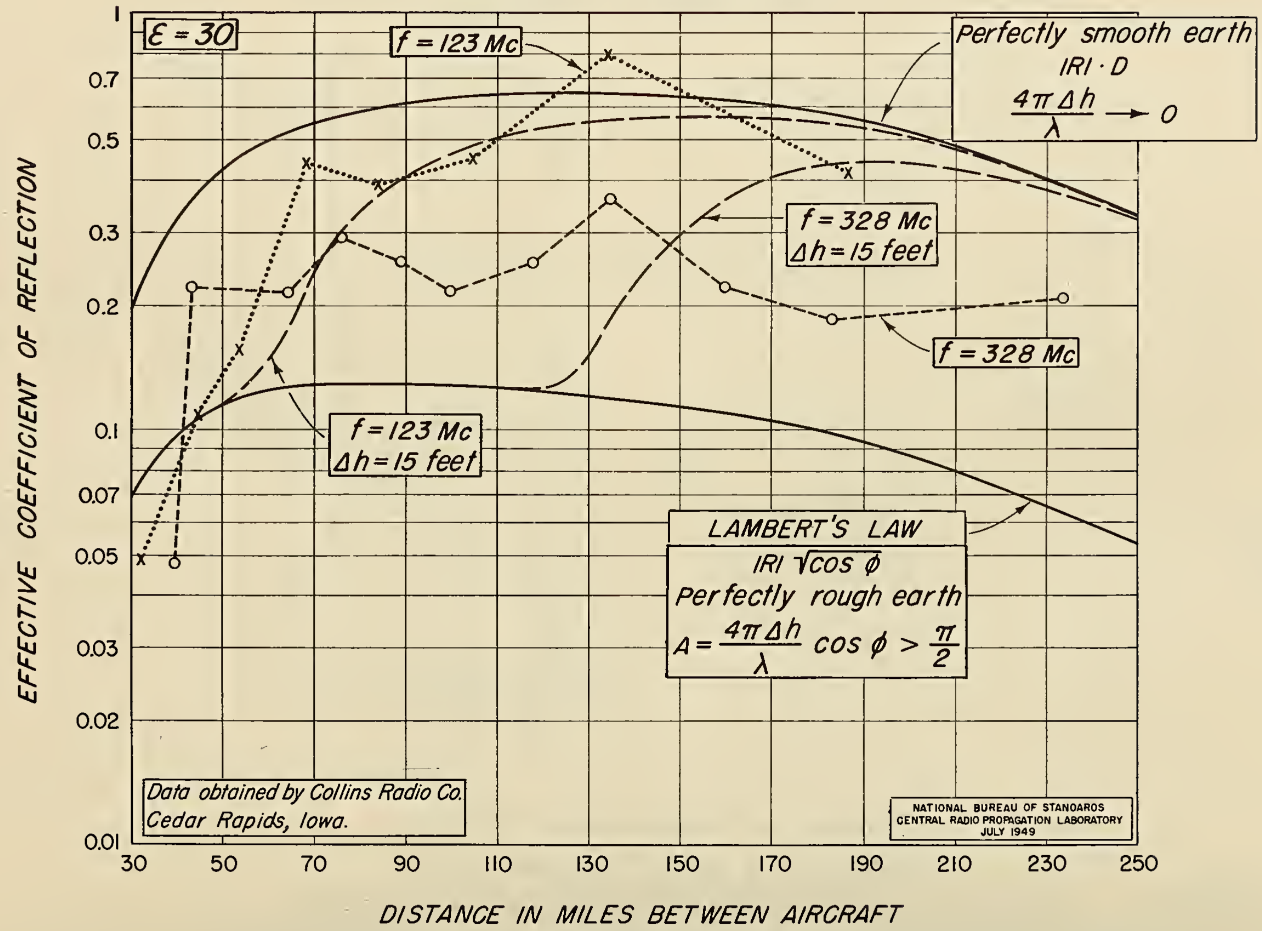


Figure 8

NBS

EFFECTIVE REFLECTION COEFFICIENT OF THE GROUND FOR AIR-TO-AIR RADIO PROPAGATION

BOTH AIRCRAFT AT AN ALTITUDE OF 9800 FEET OVER LAKE MICHIGAN
VERTICAL POLARIZATION

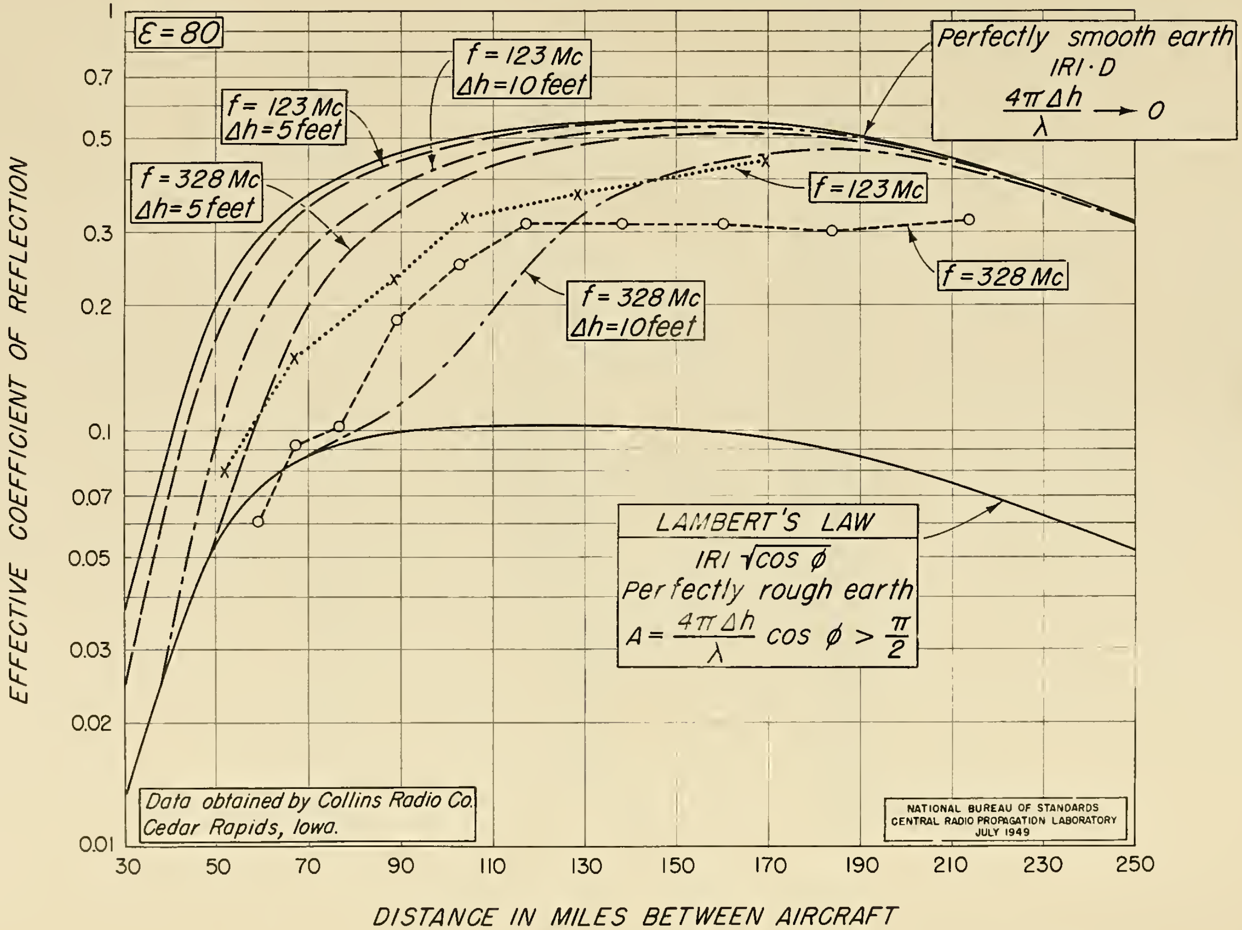


Figure 9

Supplement XXII

OBSTACLE GAIN MEASUREMENTS OVER PIKES PEAK AT 60 TO 1046 MC

By

R. S. Kirby, H. T. Dougherty and P. L. McQuate
National Bureau of Standards
Boulder, Colorado

See No. 355, page 112q, in the list of technical abstracts.

U.S. DEPARTMENT OF COMMERCE
Frederick H. Mueller, *Secretary*

NATIONAL BUREAU OF STANDARDS
A. V. Astin, *Director*

THE NATIONAL BUREAU OF STANDARDS

The scope of activities of the National Bureau of Standards at its major laboratories in Washington, D.C., and Boulder, Colorado, is suggested in the following listing of the divisions and sections engaged in technical work. In general, each section carries out specialized research, development, and engineering in the field indicated by its title. A brief description of the activities, and of the resultant publications, appears on the inside of the front cover.

WASHINGTON, D.C.

Electricity and Electronics. Resistance and Reactance. Electron Devices. Electrical Instruments. Magnetic Measurements. Dielectrics. Engineering Electronics. Electronic Instrumentation. Electrochemistry.

Optics and Metrology. Photometry and Colorimetry. Photographic Technology. Length. Engineering Metrology.

Heat. Temperature Physics. Thermodynamics. Cryogenic Physics. Rheology. Molecular Kinetics. Free Radicals Research.

Atomic and Radiation Physics. Spectroscopy. Radiometry. Mass Spectrometry. Solid State Physics. Electron Physics. Atomic Physics. Neutron Physics. Radiation Theory. Radioactivity. X-rays. High Energy Radiation. Nucleonic Instrumentation. Radiological Equipment.

Chemistry. Organic Coatings. Surface Chemistry. Organic Chemistry. Analytical Chemistry. Inorganic Chemistry. Electrodeposition. Molecular Structure and Properties of Gases. Physical Chemistry. Thermochemistry. Spectrochemistry. Pure Substances.

Mechanics. Sound. Mechanical Instruments. Fluid Mechanics. Engineering Mechanics. Mass and Scale. Capacity, Density, and Fluid Meters. Combustion Controls.

Organic and Fibrous Materials. Rubber. Textiles. Paper. Leather. Testing and Specifications. Polymer Structure. Plastics. Dental Research.

Metallurgy. Thermal Metallurgy. Chemical Metallurgy. Mechanical Metallurgy. Corrosion. Metal Physics.

Mineral Products. Engineering Ceramics. Glass. Refractories. Enameled Metals. Constitution and Microstructure.

Building Technology. Structural Engineering. Fire Protection. Air Conditioning, Heating, and Refrigeration. Floor, Roof, and Wall Coverings. Codes and Safety Standards. Heat Transfer. Concreting Materials.

Applied Mathematics. Numerical Analysis. Computation. Statistical Engineering. Mathematical Physics.

Data Processing Systems. SEAC Engineering Group. Components and Techniques. Digital Circuitry. Digital Systems. Analog Systems. Application Engineering.

• Office of Basic Instrumentation. • Office of Weights and Measures.

BOULDER, COLORADO

Cryogenic Engineering. Cryogenic Equipment. Cryogenic Processes. Properties of Materials. Gas Liquefaction.

Radio Propagation Physics. Upper Atmosphere Research. Ionospheric Research. Regular Propagation Services. Sun-Earth Relationships. VHF Research. Radio Warning Services. Airglow and Aurora. Radio Astronomy and Arctic Propagation.

Radio Propagation Engineering. Data Reduction Instrumentation. Modulation Research. Radio Noise. Tropospheric Measurements. Tropospheric Analysis. Propagation Obstacles Engineering. Radio-Meteorology. Lower Atmosphere Physics.

Radio Standards. High Frequency Electrical Standards. Radio Broadcast Service. High Frequency Impedance Standards. Electronic Calibration Center. Microwave Physics. Microwave Circuit Standards.

Radio Communication and Systems. Low Frequency and Very Low Frequency Research. High Frequency and Very High Frequency Research. Ultra High Frequency and Super High Frequency Research. Modulation Research. Antenna Research. Navigation Systems. Systems Analysis. Field Operations.

NBS